



**Developing integrated livestock breeding and management strategies
to improve animal health, product quality and performance in
European organic and 'low input' milk, meat and egg production**

Final report



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Executive summary

LowInputBreeds integrated breeding and management to improve animal health, product quality and performance in organic and low input milk, meat and eggs. Four technical sub-projects (SP) were evaluated for ethical, economic and environmental impact in a 5th SP, which also covered training and dissemination, including our website which lists contacts and bi-annual newsletters.

SP 1 on cattle estimated genomic breeding values with reasonable accuracy for novel functional traits, in 1500 Brown Swiss (BS) cows on low input and organic farms in Switzerland. US BS genetics significantly influenced milk fatty acid composition. Gene analysis shows no major differences between these BS cows and those on high-input farms or reference German Holstein Friesians. In the UK yields, milk quality, health and welfare was assessed for 1000 crossbred dairy cows on low-input/organic farms and preliminary analysis reveals differences between farms and within population on the same management. Simulation studies assessed the impact of natural service bulls on genetic gain and inbreeding in organic genomic breeding programs, revealing superiority in the use of genomics for AI bull selection.

The sheep SP focused on mountainous and Mediterranean areas; assessing genetic, nutritional and grazing management on a) stress resistance in robust sheep, b) integrative approaches to control intestinal nematodes, and c) meat and lamb carcasses quality. The role of genetics was evaluated within Greek Sfakiano dairy sheep for resistance to heat, parasites and mastitis - investigating scope for marker genes. Elsewhere, rustic and intensive breeds were compared for parasite resistance, carcase and meat quality, as well as the potential to exploit bioactive, tannin-rich forages and. Citrus pulp diets reduced subsequent meat lipid oxidation, changes to grazing management reduced parasite infection (e.g. transhumance practices) and improved lambs carcase and fat composition (timing of grazing and/ or fertiliser application). A few long-term studies showed potential integration of 2 or 3 factors (genetic, nutritional and/or grazing management) to control parasites or lamb quality.

SP 3 focused on pigs, identifying breeds suited to low input systems; designing dedicated breeding systems, investigating heat tolerance, reduced piglet mortality and improved meat quality by breed choice and management. Conventional breeds suited commodity organic pork production, as did prolific, leaner traditional breeds, especially if crossed with conventional white boar breeds to give leaner carcasses. Rotational breeding proved a viable structure for Dutch organic pigs, especially with AI boars ranked to an organic selection index. Genetic analyses shows breeding for heat tolerance is possible due to variation in existing lines. The effect of dam genetics and rearing on piglet mortality was assessed in both conventional and organic environments with genotype*environment interactions detected. Conventionally reared sows selected for low mortality had less piglet mortality compared with those of lower genetic merit but the opposite was found for organic sows. Saddlebacks under organic conditions produced quality, dry fermented sausage in contrast to fast growing modern hybrids, however, if the price is not adapted to carcase or processing quality, Saddlebacks may not be economic.

The SP on laying hens in free range and organic production a) developed a participatory system to optimise and test genotypes, b) optimized management for diet and feather pecking, c) extended productive life and d) assessed egg quality. Basic inputs came from farmers in France, Switzerland and The Netherlands with observations and discussions in CH and NL. Most farms benchmarked production using (on line) programs, giving a practical system to test genotypes across farms. They tend to have a long-term relationship with egg traders (CH) or rearing companies (NL); both being influential in breed choice. Brown egg strains dominated although the proportion of White Leghorns did rise. Management of organic and free-range flocks are improving with better-suited genotypes, closing the production gap on barn and cage production. Modelling suggests heavier hens might be more profitable than existing genotypes, except in organic systems with high feed costs. Protein quality is a challenge in organic diets, hindered by the EU ban on meat and bone or insect meal hence plant proteins were evaluated to replace imported soya

By developing and integrating (a) genotypes selected for performance, robustness and product quality traits, and (b) management innovations to improve 'low input' systems the project made a significant contribution towards regionally-adapted breeding strategies, compatible with sustainable production, high product quality and organic principles.

Main context and objectives – why the project?

Breeding livestock specifically for organic and 'low input' (e.g. free range, pasture based) production systems received little attention until recently. As a result, the majority of such systems use either (a) genotypes developed for 'high input' production or (b) older traditional breeds. However, it is increasingly recognised that breeding priorities differ between high and 'low input' systems. In particular improvement of functional traits such as (a) 'robustness' (e.g. resistance to biotic and abiotic stress factors, mothering ability, survival of young animals, longevity, fertility), and (b) 'product quality' traits (including ethical qualities related to animal welfare and environmental impact related traits) have higher priority in organic and 'low input' compared to 'high input' conventional systems.

Commercial breeding companies and associations, which drive cattle, pig and poultry breed development in the conventional sector, were until recently reluctant to develop specific breeding programmes for the organic and 'low input' sector. This is due to a combination of reasons:

- high costs of developing and maintaining new breeding programmes and associated facilities (e.g. specialised production units for parent lines of cross and hybrid breeding systems),
- relatively small market (in most EU-countries organic and 'low input' systems account for less than 5% of production),
- higher diversity of production systems in the organic and 'low input' sector,
- lack of knowledge on specific breeding goals for the organic and 'low input' sector,
- lack of appropriate breeding and selection tools and concepts to improve functional traits.

A range of novel breeding and selection concepts and tools may overcome these limitations. Farmer participatory breeding systems in the pig and poultry sectors, cross breeding in dairy cows and molecular approaches such as marker assisted and genome-wide selection offer opportunities, currently not used in the organic and 'low input' sectors. These concepts and tools are thought to allow (a) significant breeding progress in relatively small populations and (b) the development of a wider range of self-contained breeding programmes focused on the specific combinations of production, animal health and welfare, and product quality traits required in different 'low input' systems throughout Europe. They are also expected to provide more rapid and appropriate breeding progress than 'in-house-nucleus schemes' started e.g. by some of the larger organic pig producers in northern Europe.

However, several important challenges in organic and 'low input' livestock production systems are unlikely to be overcome by breeding alone, due to the extreme diversity and variability in 'low input' and organic systems compared to the conventional situation. The variability of consumers' demand in time can also be an issue. This means that in many situations, integrated approaches have to be used in order to introduce flexibility and adaptability into the production systems. It is therefore important to (a) combine breeding with appropriate management innovations and (b) quantify genotype-by-environment (G*E) interactions. Such integrated approaches are needed in the following areas:

- **Animal health**

Studies in Northern Europe have shown that tanniferous forages (TF), the strategic use of clean pastures, and improved diet composition may significantly reduce parasite infections in sheep and their need for anthelmintic treatments. However, less research has focused on other macro-climatic regions and on the integration of feeding, management and breeding strategies.

In poultry there are indications that gastrointestinal diseases, parasites and associated mortality among birds with access to pasture is higher than in flocks kept inside.

Recent research results for dairy cows indicate certain organic and 'low input' systems have lower levels of mastitis and associated antibiotic use than high input conventional systems. However, it remained unclear to what extent this was due to differences in genotypes and/or management practices. There is also limited information on the effect of both breed and management on mastitis in 'low input' dairy sheep production. In pigs, outside rearing systems results in less post weaning diarrhoea, but there is little information on G*E interactions with respect to gastrointestinal and other diseases in both pigs and poultry.

- **Nutritional, sensory, welfare and ethical quality of livestock products**

Positive effects of forage intake on the fatty acid and fat soluble antioxidant composition of milk, meat, and eggs have recently been reported. The use of tannin rich forages has also been associated with a reduction of methane production from ruminants. In contrast, certain components of typical organic or 'low input' diets have been associated with reduced carcass and sensory quality of sheep meat. Diets used in organic production systems often have a poor balance of amino acids and this has been shown to exacerbate certain animal welfare and environmental problems (e.g. feather pecking and cannibalism in laying hens, tail biting and cannibalism in pigs, and higher P excretion in poultry manure). In some livestock production systems male animals are killed and discarded shortly after birth or hatching (e.g. male chicks in laying hen production systems, bull calves in dairy cattle production). Also, spent laying hens are usually discarded after only one laying period, due to small carcass size and lack of markets for their meat. This not only increases the cost of production, but may also seriously undermine consumer confidence in the ethics of 'low input' livestock production systems.

The integrating EU-FP7 project LowInputBreeds aimed to develop integrated livestock breeding and management strategies to improve animal health, product quality and performance in European organic and 'low input' milk, meat and egg production systems through research, dissemination and training activities. The consortium included 19 academic centres of excellence and 6 industrial partners in 17 countries of which 2 ICPC and 2 industrialised third countries.

The project had four main objectives:

1. To develop and evaluate innovative breeding concepts (including genome wide and marker assisted selection, cross-, flower- and farmer participatory breeding strategies) to deliver genotypes with 'robustness' and quality traits required under 'low input' conditions. This will focus on six livestock production systems (dairy cows and beef cattle, dairy and meat sheep, pigs and laying hens) and the design of species-specific breeding strategies for different macroclimatic regions.
2. To integrate the use of improved genotypes with innovative management approaches including improved diets, feeding regimes and rearing systems. This will focus on issues where breeding or management innovations on their own are unlikely to provide satisfactory solutions (e.g. mastitis and parasite control, animal welfare problems).
3. To identify potential economic, environmental, genetic diversity/plasticity and ethical impacts of project deliverables to ensure that they are in line with different societal priorities and consumer expectations.
4. To establish an efficient training and dissemination programme aimed at rapid exploitation and application of project deliverables by the organic and 'low input' livestock industry.

Summary of the main finding:

The project was organised in 4 species-specific Subprojects (focused on objectives 1 and 2) and in one Subproject dealing with impact assessment, dissemination and training across species (objectives 3 and 4).

Subproject 1 of the LowInputBreeds project focused on dairy cattle breeding under low input conditions.

WP1.1: Development of within-breed selection systems to improve animal health, product quality and performance traits

Approximately **1500 Brown Swiss dairy cows** from 40 low input and organic farms in Switzerland were phenotyped for a comprehensive set of partly novel functional traits during six farm visits. Random regression methodology was applied to estimate genetic parameter for longitudinal Gaussian and categorical traits (Yin *et al.*, 2012), and this study revealed considerable fluctuation of genetic parameters such as heritabilities and genetic correlations across test days and/or between lactations. Further functional and behaviour traits were analysed by Kramer *et al.* (2013a) and the resulting genetic parameters and conventional breeding values form the basis for a genomic breeding value estimation for the respective traits reported by (Kramer *et al.*, 2013b). The results of this study indicate that for many of the low input traits a genomic prediction appears promising and will provide estimated breeding values with an improved accuracy. Both (Kramer *et al.*, 2014) and Erbe *et al.* (2014 unpublished) used data generated in this project to develop and compare strategies to quantify the accuracy of genomic breeding values from traits of widely different genetic architecture.

Since the project provided unique data on milk composition per udder quarter, a specific study (Kramer *et al.*, 2013a) aimed at estimating genetic parameters for this trait complex. The resulting parameters reflect very nicely the physiological background of the different milk components considered. Also, the variability of milk composition between udder quarters was considered as a potential candidate trait reflecting the physiological balance, which might be an especially relevant indicator trait under low input conditions. However, it was found that the heritability for this trait was generally low, but repeatability was medium to high, especially so for the between quarter variability of the lactose and protein content. Hence, such traits are not well suited for breeding purposes, but may be useful indicators in farm management of low input dairy herds.

The impact of US Brown Swiss genetics on milk quality from low input herds in Switzerland and the interactions with grazing intake and pasture type was also studied (Stergiadis *et al.*, unpublished). Furthermore, analysis of the haplotype inventory revealed no major differences between the haplotype and linkage disequilibrium characteristics of the low input Brown Swiss sample and the high input Brown Swiss populations and the German Holstein Friesian population used as reference (Qanbari *et al.*, 2011). Beyond that, a comparative genome wide scan for selection signatures in Brown Swiss cattle adapted to low and high input production systems (Qanbari *et al.*, 2014, unpublished) revealed that differential selection for the contrasting environment has only led to few major distinct signs of selection in the genome of Brown Swiss cattle. Significant differentiation between the populations adapted to high and low input production systems, respectively, were observed for the genes of the immunoglobulin superfamily on chromosome 1, the gene IGLL1 on chromosome 17 involved in immunoglobulin gene rearrangements, the fertility-associated gene BMPR1B on chromosome 6, and an exceptionally strong differentiation was found for the MS4A gene cluster on chromosome 29 affecting membrane protein synthesis. These results may suggest that genetic adaptation to low input conditions has taken place in relevant physiological complexes, like the immune system and the fertility complex.

Stergiadis *et al.* (2014 unpublished) reports the effect of, and interactions between, contrasting crossbreed genetics (US Brown Swiss [BS] x Improved Braunvieh [BV] x Original Braunvieh [OB]) and feeding regimes (especially grazing intake and pasture type) on milk fatty acid (FA) profiles. Concentrations of total polyunsaturated FA, total omega-3 FA and trans palmitoleic, vaccenic, α -linolenic, eicosapentaenoic and docosapentaenoic acids were higher in cows with a low proportion of BS genetics. Highest concentrations of the nutritionally desirable FA, trans palmitoleic, vaccenic and eicosapentaenoic were found for cows with a low proportion of BS genetics (0-24% and/or 25-49%) on high grazing intake

(75-100% of dry matter) diets. Multivariate analysis indicated that the proportion of OB genetics is a positive driver for nutritionally desirable monounsaturated and polyunsaturated FA while BS genetics proportion was positive driver for total and undesirable individual saturated FA. Significant genetics x feeding regime interactions for a range of FA were also detected.

WP1.2: Development of improved cross-breeding and supplementation strategies to optimise the balance between 'robustness' and performance traits

In recent years UK dairying has tended to diverge from intensive production, with high levels of supplementation, limited access to pasture and milking 3 time per day as one extreme and extensive, low-input systems relying heavily on grazing with little concentrate feed at the other end of the scale and a range of intensities in-between. Whereas high yielding Holstein cows are ideally suited to intensive production, they are totally inappropriate for low-input systems. To fully exploit grazing, such herds need to block calve to ensure peak nutritional requirements coincide with herbage growth, allowing production, fertility and health to be sustained.

As with low-input dairying in New Zealand, UK farms choose cross breeding to find cows suited to milking from grazing, although there has been limited investigation into appropriate breed combinations for differing locations or intensities, or how such crosses can be maintained in a closed herd – hence this study under LowInputBreeds. Management records and milk samples were collected from low-input (n=10) and organic (n=7) herds on 4 occasions through 2011-2012 to compare production, fertility, health and milk quality of 1069 individual cross-bred cows, with various combinations of genes. This study was delayed until logistics of collecting milk individual samples from such a large number of cows and establishing that preservative treated milk, collected for routine testing, was appropriate for fatty acid determination (Butler and Stergiadis, 2011) was an important element. Results have still to be fully analysed but initial findings were presented at this meeting. The most common breeds represented in monitored cows were Jersey (17%), Swedish or Norwegian Red (17%), Holstein (15%, since many farms were crossing from higher input herds), and NZ Friesian (14%). There were also Holstein/Friesian (10%), Friesian of unknown origin (7%), Dairy Shorthorn (7%), Ayrshire (6%), British Friesian (4%), Montbelliarde (2%) crosses and a few cows with MRI and Brown Swiss genes. If we consider the breed contribution to individual cows, Jersey genes ranged from pure bred cows to others with 12.5% Jersey genes (1 of their great-great-grandparents) with the same pattern for NZ Friesian, Dairy Shorthorn, Ayrshire and British Friesian. The contribution of Holstein genes ranged from pure bred cows to 3% and other breeds fell between these extremes.

It is well known that milk yield and composition are greatly influenced by dairy diets although an initial look at this data set (4280 records) reveals variation in milk yield, fat content and fatty acid profiles within herds at the same sampling date. This suggests a considerable genetic influence, assuming cows have access to the same feed resources. This work has been written up provisionally (Butler 2014, unpublished) but the volume of data collected over a range of production intensities offers immense scope to yield more useful results from further analysis of the findings.

Another study considered the impact of oil seed supplementation on animal health, milk yield and quality (Stergiadis *et al.*, 2014). Many studies show concentrations of nutritionally desirable fatty acids in bovine milk are lower when cows have no access to grazing, leading to seasonal fluctuations in milk quality if cows are housed for part of the year, as in many European countries. This study investigated the potential to improve fatty acid profiles of bovine milk by oilseed supplementation (rolled linseed and rapeseed) during a period of indoor feeding in both organic and conventional production systems. Both linseed and rapeseed increased milk concentrations of total monounsaturated fatty acids, vaccenic acid, oleic acid, and rumenic acid, but decreased concentrations of total and certain individual saturated fatty acids. Linseed resulted in greater changes than rapeseed and also significantly increased concentrations of α -linolenic acid, total polyunsaturated fatty acids and total omega-3 fatty acids. The response to oilseed supplementation with respect to increasing concentrations of vaccenic acid and omega-3 fatty acids appeared more efficient for organic compared with conventional diets.

WP1.3: Design of optimised breeding and management systems for different macro-climatic regions or Europe: model-based multi-criteria evaluation

The results of the parameter estimations in WP 1.1 were the basis for a study assessing the optimal design of low input breeding programs accounting for a large variety of breeding goal traits such as performance, health, fertility, behaviour, and environmental impact expressed as methane emission (Frevert et al., 2014, unpublished). Genetic correlations between production and functional traits and methane emission were taken from the study by (Yin *et al.*, 2014) based on data generated in this project. From the breeding design study it becomes evident that due to the given genetic correlation it is difficult to improve all trait complexes at the same time under different environmental conditions. Due to the strong and unfavourable genetic correlation between production and methane emission it is a challenge to have both an economically desired genetic gain in production and a limitation (or even reduction) of methane emission. It was also shown that genomic selection approaches improve this situation slightly, but do not help to fully overcome this trait antagonism. The developed tool to optimize the design of low input breeding programs will be made available as a template for the ZPLAN+ software so that interested parties can use the approach and modify and adapt the optimization according to their needs. Another simulation study (Yin *et al.*, 2014) focusses on the impact of natural service bulls on genetic gain and inbreeding in organic dairy cattle genomic breeding programs with a special focus on the relevance of genotype by environment (G x E) interactions. The overall conclusion is that in a wide range of scenarios the use of genomically selected AI bulls is the most beneficial strategy under low input or organic conditions. Only for pronounced G x E interactions and with highly accurate genomic breeding values for natural service bulls results suggest the use of genotyped organic natural service bulls in the organic and low input herds. The genetic background of growth and carcass traits in two Slovenian dual purpose cattle breeds (Slovenian Simmental and Slovenian Brown) was analysed in a study by Jevsinek Skok et al. (2014 unpublished). Here it was found that the fat mass and obesity associated gene (FTO) was associated with meat percentage in both breeds, additionally, in Slovenian Simmental cattle the FTO gene was associated with fat percentage, bone weight and live weight at slaughter and in Brown breed with carcass weight, net gain and gain from 150 kg. The FTO gene can thus be regarded as a candidate for the marker assisted selection programs in these and possibly other populations of cattle.

In this work package, three additional partners providing data and analyses from different agroclimatic zones were recruited. The group from the National Agricultural and Food Centre in Slovakia studied muscle thickness via ultrasound technology in heifers of the Slovak Pinzgau breed, which is a rustic breed able to produce heavy weaned cattle in a system of suckler cows under low input conditions. Genetic parameters estimated in these studies (Polak et al., 2013a, 2013b) suggest that ultrasound measurements can be valuable auxiliary traits in low input breeding programs for beef and dual purpose cattle. The group at the Department of Veterinary Science and Public Health at the University of Milan, Italy, studied the Carora breed, a taurine breed adapted to different climatic zones in Venezuela with a focus on the dependency of milk production, growth, and efficiency (milk yield per kg body weight) as a function of ambient temperature and humidity. The group from the Animal & Grassland Research and Innovation Centre (Teagasc) in Ireland focused on the genetic analysis of milk coagulation properties (MCP) assessed by the use of mid-infrared spectroscopy (MIRS) in Irish and Italian samples and estimated heritabilities and genetic correlations to production traits and were able to demonstrate positive relationships between MCP and milk composition (Visentin et al., 2014a, 2014b). In a further study by this partner, the effectiveness of MIRS to predict milk quality traits including free amino acids, milk protein fractions, and milk colour was tested. Prediction accuracy ranged from 0.27 (β -lactoglobulin A) to 0.56 (α -s2-casein) for milk protein fractions and from 0.12 (Threonine) to 0.72 (Valine) for free amino acids (McDermott et al., 2014a, 2014b). Overall these studies demonstrate that novel phenotyping techniques such as MIRS can help to assess innovative traits varying across production levels and agro-climatic zones, offering novel possibilities for breeding approaches.

Subproject 2: Sheep

Studies in the sheep subproject focused on production in mountainous and Mediterranean conditions, examining both the meat and milk production. Six main institutions are involved: University Newcastle upon Tyne (UNEW); FiBL (Switzerland), INRA Toulouse and Theix (France); NAGREF (Greece); University of Catania (Italy) and the University of Lincoln (New Zealand). The overall objective is to examine how the separate manipulation and then integration of genetic and/or environmental (nutrition and grazing management) components in breeding systems might help to reduce the reliance on chemical inputs in outdoor ovine production in order to improve the animal response to stress and what will be the effects on performance and quality of milk and/or meat. The response to two models of stress has been explored: either abiotic (heat stress) or biotic factors (infections with parasitic gastro intestinal nematodes).

WP2.1: Development of within breed selection systems to improve abiotic and biotic stress resistance and performance traits

The role of genetic factors has been particularly evaluated within a Mediterranean mountainous dairy sheep breed (Sfakiano sheep) in regard of resistance to heat and main diseases (gastro intestinal nematodes [GINs] and mastitis). The possible use of genetic markers in this context has also been examined. In addition, comparative studies between rustic vs more intensive breeds in regard of resistance to GINs and quality of carcasses and meat have also been performed in other countries underlining the participation of genetic components for these performances

The aim of the first study carried out in Crete (Greece) was to monitor the performance (milk quality and quantity) and robustness of Sfakiano dairy sheep under various biotic (i.e. subclinical mastitis and GIN infection) and abiotic (i.e. management and environmental conditions) stress factors. For this, over a period of 2 years (2009-2011) 10 extensive and 10 semi-intensive sheep flocks were monitored (40 ewes per flock). In monthly intervals during the course of the study management data and collected bulk milk samples were recorded via a questionnaire. Individual milk (separate per teat) and faecal samples were collected at the same intervals.

Parasitological results showed that all flocks during the course of the study were positive for GIN infections; however the parasitic burden was relatively low. The faecal egg counts (FEC, eggs/g faeces) ranged from 0 – 6540 (average 95 – 142, depending on year). Most common identified species were *Teladorsagia* spp. and *Trichostrongylus* spp. Differences identified between the autumn and winter lambing ewes and the seasonal changes in EPG can help in the design of more effective treatment schemes. Specifically for subclinical mastitis 9,700 milk samples were analyzed for milk lactose, CFU (Colony Forming Units) and SCC (Somatic Cell Count), as indicators. All milk samples with more than 400,000 somatic cells per ml were further microbiologically examined. In total, 2530 milk samples were analyzed and one or more pathogenic microorganisms were found in 53% of the samples. The udder pathogens found in frequency order were *Staphylococcus* CNS, *Staphylococcus* CPS, *Corynebacterium* spp., *Streptococcus* spp., *Enterobacteriaceae* and other microorganisms.

Significant effects of lambing period, management system and season on both biotic stress factors were identified; spring lambing animals were less affected by subclinical mastitis and more affected by gastrointestinal parasites. Moreover lambing period, management system and season had also significant effects on milk quantity and quality; the extensive flocks show a more desired milk Fatty Acid (FA) profile, while the semi-intensive flocks had more constant milk chemical composition and FA profile during lactation.

Blood samples for genetic characterisation were collected (n=1054) and examined for single nucleotide polymorphism (SNP) variation in B3ADR and DQA2 genes. The DQA2 gene is connected to parasitic infection resistance and footrot susceptibility, while the B3ADR gene to cold stress and metabolic activity. The results show extensive polymorphism variation indicating a strong potential for genetic selection. Further research is needed to pursue this goal.

WP2.2: Development of improved endoparasite management strategies based on integrating a) feed supplementation with tanniniferous forages b) strategic use of clean pastures and c) the use of parasite tolerant breeds

The general objective was to provide information to exploit tanniniferous resources to control GINs. The specific objectives aimed at addressing three main questions (1) which resources to use? (2) quantity needed? (3) origin of the variability in the AH effects? To answer these questions, three in vivo experiments were carried out to quantify effects of tannin containing (TC) forages (sainfoin and sulla) and crops (faba bean and carob pods) with a potential to control GINs. Results of different in vivo studies suggest that a threshold around 2 to 3 % of CTs in the diet (analysed after Folin Ciocalteu) is requested to obtain any AH effect. In addition, the nature/quality of tannins is also a key modulating factor to consider. Based on multiple in vitro studies using sainfoin as a model, several factors have been identified to affect the variability in the AH activity namely: i) Genetic factors (cultivars of the plant); ii) Environmental factors (phenological stages, sites of production, numbers of cuts) which can be summarized by “stress factors” to the plant; iii) Technological processes (drying, ensiling, pelleting) because of physical factors (pH, temperature, pressure) affecting the quantity/quality of tannins and thus the bioactivity

Integrated approaches aim for additive or synergic effects for a sustainable GIN control by combining two or more alternative control approaches (e.g. genetics, nutrition and management). In a first study (Werne et al., 2013a) the effectiveness of combining two tannin containing feeds was assessed. Sainfoin (*Onobrychis viciifolia*) and faba bean (*Vicia faba*) were fed as single diet or in combination to periparturient ewes for a period of 25 days. The FEC of these animals was repeatedly assessed during the trial. Compared to the control group (ryegrass-clover), the sainfoin fed animals showed a 54.7% reduced FEC ($p < 0.001$). The combined tannin group (sainfoin and faba bean) showed a 40% reduced FEC ($p < 0.001$) compared to the control group. However, there was no difference between the single sainfoin and the combined tannin group. Therefore no additive or synergic effects could be shown by the combination of the tannin feeds.

In a second trial (Werne *et al.*, 2013), the integrated control approach was the use of a less susceptible sheep breed (Red Engadine Sheep; RES) compared to a high performing breed (Swiss White Alpine; SWA) and a forage rich in condensed tannins (sainfoin). Two studies were conducted, one to test the effect of a reduced sainfoin percentage on the FEC and another to test the effect of a 100% sainfoin diet on the nematode numbers of the experimental sheep. It could be shown that a proportion of 55% sainfoin in the diet reduced the FEC of these animals significantly compared to control. It was also revealed that a 100% sainfoin diet can reduce the numbers of *Teladorsagia* spp. ($p = 0.049$) and *Nematodirus* spp. ($p < 0.001$) compared to the control group. Irrespective of sainfoin feeding, the RES harboured lower numbers of *Haemonchus* spp. ($p = 0.035$) and *Trichostrongylus* spp. ($p = 0.003$) compared to the SWA. As the effect of breed and sainfoin was not combined in one nematode genus, we consider the effects as non-additive. The considerable effects of the sainfoin feeding and the RES, however, suggest the use of either strategy for an alternative GIN control. Overall, the positive effect of sainfoin on FEC and worm numbers could be consolidated in GIN infected sheep. Beyond that, additive effects induced by the integrated approach “robust breed and alpine pastures” could be shown.

In a third study (Werne et al., in prep), the potential benefits of the combination of a partly resistant breed and the strategic use of pastures with low infection level was assessed. Two flocks of lambs, consisting of native RES and SWA, were grazed on alpine ($n = 62$) and lowland ($n = 55$) pastures for 82 days. FEC were repeatedly performed and weight gain was recorded over the entire trial. After a grazing period of 50 days, all lambs with a FEC above 1000 were drenched with an anthelmintic (AH) for welfare reasons and ‘refugia’ provision. None of the lambs on alpine pastures required AH treatment, whereas 56% of the lowland lambs needed drenching according to our threshold (χ^2 , $p < 0.01$). Due to AH intervention, repeatedly measured FEC did not differ between grazing sites. Regardless of grazing site, RES had significantly lower FEC over the entire trial ($p < 0.001$) compared to SWA, and the proportion of drenched RES was significantly lower compared to the proportion of drenched SWA ($p = 0.001$). The grazing site had a strong effect on weight gain ($p < 0.001$); transhumant lambs gained less weight

compared to lowland lambs (3.79 kg). Within the lowland flock, the SWA gained significantly more weight (3.02 kg) compared to RES ($p < 0.001$). Concerning the alpine flock, the RES had a slightly better weight gain (0.95 kg) compared to SWA, but the difference was not significant ($p = 0.089$). The drenched lambs gained more weight compared to undrenched lambs ($p = 0.004$; 1.87 kg). The nematode populations of 44 never drenched lambs were determined. *Teladorsagia circumcincta* ($p < 0.001$) and *Nematodirus* spp. ($p = 0.029$) were more numerous in the transhumant flock compared to the lowland flock. In contrast, the transhumant flock harboured significantly less *Trichostrongylus colubriformis* than the lowland flock ($p < 0.001$). *Haemonchus* spp. numbers were very low in both groups and did not differ between grazing sites. The finding that no transhumant lambs required AH treatment after 50 days of grazing indicated a low infection level of the alpine pastures. Due to the overall lower FEC and the noteworthy good weight gains of RES on alpine pastures, this breed was found to be an option for alpine sheep husbandry.

These experiments in controlled conditions were completed by results of a field study performed in France with a similar experimental design applied for 3 years (2010- 2012). The aim of the study was to examine the effect of the distribution for 10 days of sainfoin hay on nematode infections at weaning - either by acting directly on the animals consuming the sainfoin, or by delayed effects because of reduced pasture contamination.

Overall, the results obtained under a wide range of climatic/agronomical conditions for the availability of TC resources and for the epidemiology of GIN parasites have shown/confirmed that i) TC resources are active to affect the biology of GINs, but these AH effects never reached 100% efficacy, whatever is the target key stages of GINs; ii) a variability in results is observed because of a range of genetic, environmental and technological factors ; iii) such variability can affect the availability of locally grown resources with AH effects when needed. Therefore, to promote the implementation of TR resources in sheep breeding to control GINs, there is a strong need to develop methods to better characterize the resources in order to use as much as possible standardized resources.

WP2.3. Development of strategies to improve lamb meat quality in sheep production systems based on optimizing a) TF feed supplementation b) grazing regimes and c) the use of stress tolerant breeds

A first study compared the sensory qualities of meat and carcasses from pasture-fed lambs reared organically or conventionally (O vs. C) at 2 levels of herbage availability (High H vs. Low L). Mean lamb growth profile was kept similar between the two production systems. The experiment was conducted over 2 years from weaning until slaughter with 12 OH, OL, CH and CL Limousine castrated lambs each year. The O and C treatments differed in the level of on-pasture mineral N fertilisation. The H and L pastures were rotationnally managed to lead to a mean lamb age at slaughter of 5 and 6 months in the H and L groups respectively. The level of parasite infection was individually surveyed every 15 days using faecal samples and lambs with parasite eggs per gram faeces higher than 550 received an anthelmintic treatment. Sensory evaluation indicated that the overall liking of loin chops was lower in the O than in the C treatment. Redness of longissimus thoracis et lumborum muscle after 2h blooming was higher in the L than in the H treatment. The low level of herbage availability led to a higher use of chemical anthelmintics. These results shed some light on the potential effects of the intensification of organic farming via an increase in stocking rate (Prache et al., 2012).

A second study compared the sensory qualities of meat and carcasses from pasture-fed lambs reared organically or conventionally (O vs. C) at 2 levels of barley supplementation (High: 300 g vs. Low: 0). Mean lamb growth profile was kept similar between the two production systems. The experiment was conducted over 2 years from weaning until slaughter with 12 OH, OL, CH and CL Limousine male lambs each year. The O and C treatments differed in the level of on-pasture mineral N fertilisation. The pastures were rotationnally managed to lead to a mean lamb age at slaughter of 5 months in the two unsupplemented groups. The level of parasite infection was individually surveyed every 15 days using faecal samples and lambs with parasite eggs per gram faeces higher than 550 received an anthelmintic treatment. The analysis of the results is still being processed.

A third study investigated i) the dose-dependent response in lamb meat of stable nitrogen isotope ratio to the dietary proportion of legumes, and the ability of the nitrogen isotope signature of the meat to authenticate meat produced from legume-rich diets and ii) the response of fat skatole and indole concentration and chop sensory attributes to the dietary level of fresh alfalfa in grazing lambs. Four groups of nine male Romane lambs grazing a cocksfoot pasture were supplemented with different levels of fresh alfalfa forage to obtain four dietary proportions of alfalfa (0%, 25%, 50% and 75%) for 98 days on average before slaughter (groups L0, L25, L50 and L75). We measured the stable nitrogen isotope ratio in the forages and in the longissimus thoracis et lumborum muscle. The $\delta^{15}\text{N}$ value of the meat decreased linearly with the dietary proportion of alfalfa. The distribution of the $\delta^{15}\text{N}$ values of the meat discriminated all the L0 lambs from the L75 lambs, and gave a correct classification score of 85.3% comparing lambs that ate alfalfa with those that did not (Devincenzi *et al.*, 2014). Perirenal fat skatole concentration was higher for lambs that consumed alfalfa than for those that consumed only cocksfoot. The intensity of 'animal' odour in the lean part of the chop and of 'animal' flavour in both the lean and fat parts of the chop, evaluated by a trained sensory panel, increased from the lowest level of alfalfa supplementation onwards and did not increase further with increasing levels of alfalfa supplementation. The outcome of this study therefore suggests that these sensory attributes may reach a plateau when perirenal fat skatole concentration is in the range 0.16-0.24 $\mu\text{g/g}$ of liquid fat (Devincenzi *et al.*, 2014).

A fourth study investigated on the possibility of restricting the daily duration of grazing time on the performances and meat quality parameters of growing lambs. This strategy might be of interest in order to limit grazing pressure and to reduce the costs that, in some instances, arise from attending the flock at pasture. One group of lambs grazed on a ryegrass pasture for 8 hours a day (8h). Two other groups of lambs grazed other parcels of the same pasture for 4 hours either in the morning or in the afternoon (4h-AM and 4h-PM). All the details can be found in the published papers resulting from the study. In summary, it was demonstrated that restricting the daily grazing duration to 4 hours in the afternoon improved the nutritional traits of meat by increasing the concentration of polyunsaturated fatty acids, which was explained considering the daily pattern of variation in the chemical composition of plants (Vasta *et al.*, 2012b). Additionally, the analysis of volatile organic compounds in carcass fat allowed to perfectly discriminate all the 3 groups of grazing lambs (Vasta *et al.*, 2012a). Furthermore, restricting the grazing duration to the sole afternoon did not compromise some important production performances, such as carcass weight, nor the shelf life of meat (Luciano *et al.*, 2012). Finally we wanted to test if phenolic compounds naturally present in grazed herbage could be bioavailable in lamb and could contribute to the high antioxidant status generally associated to pasture-feeding (López-Andrés *et al.*, 2014). We therefore analysed liver and plasma from grazing lambs (8h group) and from lambs fed concentrates in stall. Feeding pasture improved the antioxidant status of liver and plasma; however, none of the phenolics found in the feeds could be detected in the tissues.

A sixth study focused on the use of Mediterranean agro-industrial by products as alternative feed resources in the formulation of concentrate-based diets for growing lambs and on their effects on lamb production performances and meat quality. All the details can be found in the published and submitted papers resulting from the study. Briefly, one group of lambs was fed with conventional concentrate feeds, while other 4 groups received diets in which cereals were partially replaced with 24% and 35% of either citrus pulp or carob pulp. The inclusion of citrus and carob pulp in the diet did not compromise any of the assessed growth and production parameters, which highlight that these by-products can find application in lamb feeding. Also, the occurrence of bioactive molecules in citrus pulp allowed the shelf-life of meat to be extended, by reducing the oxidative deterioration of muscle lipids and proteins over time of storage duration (Inserra *et al.*, 2014) (Gravador *et al.*, 2014). Additionally, the inclusion of citrus pulp in the diet improved meat fatty acid composition, with a higher deposition of polyunsaturated n-3 fatty acids and rumenic acid (CLA) and a lower content of saturated fatty acids. The analysis of fatty acids in both the feeds and in the ruminal content and blood of lambs allowed to explain our results both by a higher content of n-3 fatty acids in citrus pulp compared to cereals and by an effect of citrus pulp in reducing the ruminal conversion of dietary unsaturated fatty acids into saturated fatty acids (Lanza *et al.*-submitted). Regarding carob pulp, it was found that its inclusion in the diet improved the fatty acid

composition of meat, as above observed for citrus pulp. Moreover, the shelf life of meat was not compromised (Gravador et al., submitted).

A seventh study was performed in collaboration with FiBL. The University of Catania has determined the fatty acid composition of meat from lambs of the second study described under W.P. 2.2 (sainfoin treatment for high-performing or susceptible breeds). Forty-eight lambs were randomly selected from this study for assessment of meat fatty acid composition. The results of this study show that the integration of tannins rich forages for parasite control in sheep may lightly influence meat quality. In particular, the levels of rumenic acid, linoleic acid, total n-6 fatty acids and the n-6/n-3 ratio were higher in lambs that in the sainfoin treatment, regardless of the breed. The above results might be explained either by a different fatty acid composition in the feeds offered to lambs, or by peculiar effects of tannins present at high levels in the sainfoin on the ruminal biohydrogenation of fatty acids.

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Subproject 3: Pigs

The objectives of the pig subproject were to identify suitable breeds for low input systems; design dedicated breeding systems; investigate possibilities to breed for heat tolerant sows; reduce piglet mortality by breeding and management; improve product quality by breed choice and feeding regime.

WP3.1: Identification of suitable breeds and development of a breeding system to improve pig survival and robustness related traits in small populations

Results from literature and surveys show that conventional breeds are well suited for commodity organic pork production in temperate climates with a controlled production environment (Leenhouwers and Merks, 2013). Conventional breeds may be less suitable in more free-range or extensive environments as found in Eastern and Southern Europe, where large litter sizes pose a risk for piglet mortality. Also the climatic conditions in these regions may be unfavourable. In cold winters, their low fat cover gives them poor protection against cold and in hot summers their lack of skin pigment makes them sensitive to sunburn (Leenhouwers and Merks, 2013). The prolific and leaner traditional breeds are suitable for commodity organic pork production, especially when crossed with conventional white boar breeds to give some extra leanness to the carcass. The fatter traditional breeds are unsuitable for commodity organic pork production due to their low fertility and high carcass fatness, but offer extra added value by their specific meat and fat quality (Leenhouwers and Merks, 2013). Moreover, their black skin pigment makes them well adapted to be reared outdoors in hot climates as found in Southern European regions.

Rotational breeding systems have proven to be a viable breeding structure for the Dutch organic pig sector, especially in combination with AI boars that are ranked according to an organic selection index (Leenhouwers *et al.*, 2011). In rotational breeding systems, the 'best' sows in the herd are selected as mother of the next generation of gilts and the breed of boar is changed (rotated) each generation. A rotation breeding system is an example of a 'closed' system with on-farm sow replacement. Once the rotational program is established, the herd remains closed and only boar semen needs to be purchased for production of replacement gilts or slaughter pigs (Leenhouwers, 2013). In rotation breeding systems, breeding stock originates from a conventional breeding program, but replacement gilts are selected in an organic environment which gives advantages in terms of environment-specific adaptation. Currently, around 50% of the Dutch organic pig herds are using the rotational breeding system called 'TOPIGS EkoFok' (Leenhouwers, 2014 unpublished). The farmers use TOPIGS Yorkshire and Landrace sow lines with the highest genetic merit for desirable traits (e.g. mothering ability, piglet vitality, sow longevity) for organic pig production (Leenhouwers, 2014 unpublished).

During the course of the LowInputBreeds project, a start was made with the development of a new robust sow line that is a hybrid of two Yorkshire lines. One of these lines is bred according to a breeding goal that puts emphasis on robustness traits such as heat stress resistance, sow longevity, feed intake and leg quality. This type of sow line is especially suitable for the more challenging production environments, such as organic and/or low input system. Currently, the sow line is being produced (amongst others) in Spain, Portugal, South Africa, Costa Rica and Colombia (Leenhouwers, 2014 unpublished).

In commercial operations, it is not a common practice to identify finishing pigs individually and to maintain pedigree records (Harlizius *et al.*, 2011). Individual identification of piglets at birth with ear tags or tattoos is too expensive. However, genetic selection for traits with low incidence, such as finisher mortality (2-5% of all finisher pigs die before being marketed) requires records from a large number (>100,000) of finishing pigs. For these traits, large progeny groups per sire (1,000 to 2,000) are needed to ensure a more precise estimate of incidence (Harlizius *et al.*, 2011). The solution may reside in retrospective assignment of the true sire (paternal identification) for affected animals only. This type of approach could substantially reduce the costs of trait recording in finishing pigs (Harlizius *et al.*, 2011). During the LowInputBreeds project, a commercial 430 DNA chip (i.e. a so-called Single Nucleotide Polymorphism SNP chip) was developed that enables tracing dead finisher pigs back the sire of origin. Subsequently, sires with unfavourable effects on mortality of their offspring can be excluded from the breeding program. In parallel with the development of this SNP chip, databases were developed that can

store large amounts of genotyping data that are generated during these type of genomic selection processes. Also, a software program was implemented that enables tracing dead pigs to their father, based on their SNP fingerprint. A proof of principle study on 4 larger farms indicated that the genetic fingerprinting approach is successful under practical conditions. This approach is planned to be included in the breeding program of TOPIGS breeding company.

Pig breeding programs have to breed pigs capable of facing heat stress challenges during their productive life (Bloemhof *et al.*, 2012). Management practices such as cooling offer one option to reduce heat stress and warrant performance during hot seasons. A more sustainable alternative is to breed sows for improved heat tolerance. Within the LowInputBreeds project, a PhD thesis was completed that aimed to investigate the genetics aspects of heat tolerance in sows (Bloemhof *et al.*, 2013). A model was developed that was used to estimate upper critical temperatures for sows' reproductive performance (Bloemhof *et al.*, 2012). Additionally the possibility to breed for reduced heat tolerance of sows was investigated. Therefore heritability for the random regression slope of farrowing rate against increasing temperature at day of insemination (= heat tolerance) and the genetic correlation between farrowing rate and heat tolerance was estimated (Bloemhof *et al.*, 2012). Commercial production pigs are crossbreds farmed all over the world. In contrast, selection is practiced mainly in temperate climates, in nucleus herds using purebred pigs. The success of genetic selection depends on how much genetic progress is realized in crossbred pigs. Within the PhD thesis, genetic correlations for farrowing rate between purebreds and crossbreds were estimated (Bloemhof *et al.*, 2013). The main conclusion of the research was that it is possible to select for improved heat resistance in addition to improved commercial production levels in commercial pigs. However, genetic correlation between production in temperate and hot climates is high. This high correlation implies that, within-line, pigs with the best performance in a hot climate will be the best in temperate climate too. Most important for the success of a pig breeding program is to define appropriate breeding goals which are based on the environment(s) that market pigs are expected to perform in. The overall data collection for the genetic evaluation needs to be done in those specific environments and this will favour pigs which are able to produce over more than one specific environment (Bloemhof *et al.*, 2013). In Brazil, a study was carried out that investigated the molecular mechanisms that explain differences in heat stress resistance of grower-finisher pigs (Weller *et al.*, 2013). The effects of temperature and different levels of available phosphorus on the expression of nine genes encoding electron transport chain proteins in the Longissimus dorsi muscle of pigs were investigated. Results showed that irrespective of growing phase, the expression of six genes was lower at high temperature than at thermoneutrality. The lower expression of these genes under high temperatures evidences the effects of heat stress by decreasing oxidative metabolism, through adaptive physiological mechanisms in order to reduce heat production. The study presented strong evidence that phosphorus and thermal environments are key factors to regulate oxidative phosphorylation with direct implications on animal performance (Weller *et al.*, 2013).

WP3.2: Development of management innovations (gilt rearing and lactation systems) on mothering ability of sows, and piglet losses

In organic and low input systems, health and survival are at risk in piglets shortly after birth and weaning. Increasing litter sizes, lower birth weights and suboptimal climatic conditions increase the risk for perinatal mortality. Post weaning, the protein provision and housing conditions are often suboptimal (Vermeer *et al.* 2014 unpublished). WP3.2 focused on developing management components (gilt rearing and piglet lactation systems) with the aim to improve piglet survival in organic and 'low input' of pig productions systems. The main objectives were to (1) determine the effects of contrasting gilt rearing systems on the health and welfare and productivity of pigs in 'low input' systems and (2) to determine the effects of sow genotype and piglet environment during weaning/lactation on piglet health, welfare, mortality and performance. Gilts were born and reared until first mating under conventional or organic conditions to affect future maternal behaviour. Sow genotypes differed in the sense that fathers of these gilts had either high or low breeding values for piglet survival. Three different piglet environment were tested: (1) suckling piglets were born and kept indoors in pens with straw bedding according to EU organic standards; (2) pigs with access to an outdoor run; and (3) pigs with access to an outdoor run including access to pasture to affect gut health after weaning. Preliminary results on the effect of gilts'

rearing environment and genetic merit for mortality on pre-weaning piglet mortality in conventional vs. organic environments show genotype by environment interactions (Vermeer et al. 2014, unpublished). Piglet mortality in sows reared in conventional environments was higher for offspring with high vs. low genetic merit for mortality. The opposite was observed for sows reared in organic environments.

WP3.3: Effect of traditional, improved and standard hybrid genotypes and standard hybrid genotypes and feeding regimes on carcass, meat and fat quality

Studies on the effect of breed on dry fermented sausage quality show that under organic farming conditions, Saddlebacks are suitable for heavy (150-170 kg) pig production to produce dry fermented sausages (Schwalm *et al.*, 2013a; Schwalm *et al.*, 2013b). However, as long as the pay-out price is not adapted to carcass quality or the suitability for processing, the use of Saddlebacks will not be interesting from an economic point of view. From the viewpoint of meat and especially of fat quality, modern hybrids have sub-optimal characteristics for dry fermented sausage production, whereas old purebred Saddlebacks are well suited. This is also true for carcass quality: Saddlebacks have sufficient fat quantities, whereas the modern hybrids represent the lower limit (Schwalm *et al.*, 2013b)).

The level of nutritionally-desirable, polyunsaturated fatty acids (PUFA) (including n-3 fatty acids is important in fresh pork products and can be increased by inclusion of fresh forage/herbage in the pig diet. These compounds have been associated with health benefits such as a reduced risk of cardiovascular disease, cancer and arthritis in humans. There is very little information on the effect of including forages into diets on contrasting pig breeds/genotypes (and virtually none for most traditional breeds).

For organic and 'low input' fresh pork production, sensory characteristics are also important to satisfy consumer expectations and/or maintain price premiums. There has been little research into the factors influencing pork flavour quality. One compound that negatively affects pork flavour is skatole. A range of known risk factors for skatole production are more common in 'low input' and especially organic systems. These include pig genotypes/lines with low lean tissue growth rate, excess supply of dietary protein and poor hygienic conditions

A survey was carried out of fat quality parameters (fatty acid composition and skatole) in fat samples taken from carcasses of pigs produced in low input and organic systems in UK, Spain and Austria. A total of 434 samples were analysed for Skatole content by GSMS and a similar number by GC for fatty acid content. Early results from analysis by general linear regression of log transformed skatole results indicated in the UK an effect of gender (higher values in entire males than in females, $P < 0.001$) but no effect of production system (outdoor paddock vs indoor straw yard systems). In Austrian samples there was a significant effect of both production system (higher values in indoor pens with concrete runs than in paddock systems, $P = 0.010$) and gender (higher values in castrates than in females, $P = 0.008$). Mallorcan samples produced low values in general for a traditional breed, however there was an effect of outdoor intensity (higher values in more intensive systems, $p = 0.002$) but no effect of gender (Holmes *et al* unpublished). Results of fatty acid analysis are currently awaiting completion.

Subproject 4: Laying hens

The poultry project aimed at (a) developing a participatory system to test and optimize genotypes of laying hens for free range and organic systems, (b) optimize management for free range and organic farms with specific emphasis on diets and feather pecking, (c) analyse how the productive life of laying hens can be extended and (d) analyse egg quality characteristics.

WP4.1 Development of a farmer participatory breeding system to improve productivity, health and welfare and egg quality related traits

Basic inputs were interviews with farmers in France, Switzerland and The Netherlands, and observations and discussions during visits of farms in Switzerland and The Netherlands. Besides, trials with alternative genotypes and moulting were carried out, as well as analyses of the fatty acid content of specific egg samples from the farms.

The majority of farms use data management programs, more and more on-line and able to produce bench mark information on production. When this information is shared, a practical system for testing of genotypes can become available. Such a system will benefit from regular workshops with farmers, hatcheries, egg traders and breeding companies as arranged in this project to discuss results and thus act as a network for optimizing management during rearing and production and breeding goals. In the network farmers emphasized the importance of robust and heavier hens. This was accompanied by a desire to raise and market the cockerels (brothers of laying hens), which are now almost all killed at hatch (also a topic in WP 5.2, ethical considerations). (Leenstra et al., 2014, unpublished)

Farmers tend to have a long term relationship with egg traders (Switzerland), rearing companies (The Netherlands) or integrations (France) and these organisations are important in choosing the genotypes.

Although brown egg laying strains are the majority on free range and organic farms in the 3 countries examined, white Leghorn type birds are becoming more popular and the proportion of White Leghorn flocks is increasing. From the results of the project it is clear that White Leghorn type birds perform relatively well on free range and organic farms, although they have on average a lower body weight than brown egg layers. Unfortunately, the market for free range and organic eggs is very much focussed on brown shelled eggs in France and The Netherlands. (van Niekerk et al., in prep)

Three alternative genotypes, considered to be more robust, and being heavier than current genotypes, were tested on a number of (small) farms in The Netherlands. In none of the cases this was an improvement. Egg production was lower, mortality higher and feather condition often worse. During the project the gap in production between free range and organic on the one hand and barn and cage production on the other decreased, indicating that management of organic and free range flocks improved and available genotypes were more adapted to organic and free range conditions. (Visscher et al., in prep)

Especially management during rearing and the transition from the rearing to laying phase improved. Model calculations indicated that only for organic systems and with current feed prices a heavier hen might be more profitable than current genotypes. Opportunities to raise and market cockerels were incorporated in the project. Raising of cockerels is very well possible and they can yield a distinguished product. However, rearing cockerels requires more resources and yields more environmental pollution than the same quantity of meat from broilers, and production costs are more than double that of broilers. A system with dual purpose chickens (taking egg and meat production together) is even less efficient than that of raising cockerels of specialized layer strains, which is less efficient than egg and meat production from specialized genotypes. (Leenstra et al., 2014)

To identify important management factors 169 flocks on 80 farms have been monitored, from which 85 flocks on 38 farms in Switzerland and 84 flocks on 42 farms in The Netherlands. From these flocks 69 were on free range farms and 100 were on organic farms. We collected information on genotype, housing, feeding, production, egg quality and mortality. Per farm, at an age between 44 to 62 weeks, we scored 50 animals for comb wounds, keel bone deviations, foot pad wounds, belly wounds, feather damage and body weight. There were 5 different brown genotypes (86 flocks), 2 white genotypes (35

flocks), 2 silvers (20 flocks) and 1 black genotype (1 flock). Twenty seven flocks consisted of 2 genotypes, mostly brown and white. We saw preferences such as whites in Switzerland and silvers on Dutch organic farms, but all genotypes were commercially available laying hens, which are also used in barn and cage housing. There are no special organic or low input breeds used. Mortality at 70 weeks of age was 6.7% in Switzerland and 8.8% in The Netherlands. If free range is compared to organic, then mortality is the same (7.6%). Number of eggs per housed hen was higher in free range (304.0), while feed intake was lowest in free range (120.6) at 70 weeks of age, compared to organic (respectively 295.7 and 124.6). Swiss hens had less wounds than Dutch hens, but we also saw a genotype effect. Mixed flocks had best feather cover (19.43 of a maximum of 24), followed by whites (18.61). Brown and silver hens scored about the same (resp. 17.90 and 17.29). Difference in feather scorings may be caused by differences in propensity to feather pecking behaviour, but numbers of feathers per cm² or colour of the feathers may also influence damage (Leenstra *et al.*, 2012).

The effects of management factors, like type of rearing system, beak treatment, range access, day light, provision of roughage and stones, presence of red mite, were examined. For example, a good feather cover is very well possible with hens with intact beaks and day light in the house is an important factor for good feather cover. Hens that are reared in aviary systems have less damage to their keel bone than hens that are raised in floor systems. (van Niekerk *et al.*, in prep)

WP4.2 Effects of, and interactions between, layer genotypes, feeding regimes and expanded productive period on performance and animal health and welfare

In organic production it is difficult to provide the hens with the right quality of protein. As it is not allowed to add synthetic amino acids, in general the protein content of organic diets is too high for the hens to maintain a stable gut health. Meat and bone meal or insect meal would be helpful, and at the start of the project the prospects for utilisation of meat and bone meal were positive. However, meat and bone meal and insects are for the time being in the EU not allowed in poultry diets. Fish meal and whey are other options, but quite expensive. Several types of plant protein are now evaluated as possible replacement for imported soya (Leenstra, 2013).

There were no clear differences between the commercial genotypes in feather pecking and many flocks have a good feather cover. As feather pecking is a serious welfare problem and promising alternative protein sources became not available we decided not to do experiments with (experimental) high feather pecking lines and diets differing in protein source and content.

A major ethical problem of organic and conventional free-range egg production is the discarding of laying hens at around 70 weeks of age. This practice of annual cycles facilitates production planning and helps standardizing egg size and shell quality, but it also produces large numbers of spent hens and, indirectly, male day old chicks that have to be killed. Moulting or keeping laying hens for prolonged periods are two approaches to reduce this problem.

While animal welfare during the moulting period has been studied, less is known about the impact of 'welfare-friendly' moulting on (a) health and immune status during the second laying period (e.g. susceptibility to endoparasites), (b) productivity of laying hens and (c) egg nutritional quality. The second laying period of a moulted flock often only lasts for 30 weeks. Due to breeding the productive live of hens is expanded gradually. Depending on the condition of the flock, egg prices and prices of young laying hens, with current genotypes the 1st laying period can also be expanded by up to 30 weeks without moulting. Within the performance recording network established within LowInputBreeds in the Netherlands and Switzerland health and welfare parameters were recorded for moulted flocks (field study). In addition, an experimental study evaluating mainly health and egg quality characteristics was carried out with small groups of animals coming from moulted flocks at different ages in the first and second laying cycle. In the field study, laying periods of about 17% of the flocks were expanded (with or without moulting). In Switzerland, farmers indicated this was mainly because of production planning while in the Netherlands it was mainly for economic reasons. The laying period was extended to 85-90 weeks (without moulting) and to about 100 weeks (with moulting). Flocks were moulted according to a 'welfare-friendly' protocol which granted access to water, oyster shells and wheat bran during the whole

process and a minimum day length of 6 hours. Feather and wound scores were good or even very good in the field flocks during both cycles (on average >3.5 on a scale of 1/bad to 4/very good) and mortality was low (5% in 1st cycle and 4% in 2nd cycle, including moulting period). First analyses of the experimental study indicate that there is no additional build-up of worm burdens during prolonged laying periods. Expanding the laying period with or without moulting therefore seems to be a good option to mitigate logistic and economic problems without compromising animal health and welfare. As a side-effect it also reduces the number of day-old male chicks to be killed. (Maurer et al., in prep)

WP4.3 Effects of, and interactions between, layer genotypes and management innovations on egg quality

Shell quality, yolk colour and Haugh Units are important egg quality characteristics. In our survey there were some differences between the two countries, but not clearly between systems or genotypes. Yolk colour and composition is very much dependent on nutrition of the hens. Health benefits of polyunsaturated fatty acids (PUFA) and especially omega-3 (n-3) fatty acids (Simopoulos, 2002) have increased consumers' preference for functional foods. Previous research has shown that egg fatty acid (FA) composition can be manipulated by a variety of factors, such as season (Mugnai et al., 2014) and strain (Grobas et al., 2001), while the effect of management system (e.g. conventional, organic, low-input) is rather ambiguous (Anderson, 2011; Samman et al., 2009).

We examined the effect of season (winter, summer) and layer's genotype (Lohmann Selected Leghorn, Lohmann Brown Classic (LBC), H&N Super Nick) in free range or organic systems on the FA profile of eggs. Eggs were collected from 13 Swiss flocks within the EU-LowInputBreeds project. Preliminary results showed that PUFA concentrations, and in particular omega-6 (n-6) and n-3, were significantly higher while monounsaturated FA concentrations were significantly lower in organic eggs compared with free range eggs. However, the nutritionally relevant n-6/n-3 ratio was not significantly different between systems. Season also had a significant effect on FA composition; eggs produced in winter showed higher values of PUFA (both n-3 and n-6). Layer genotypes only significantly affected egg saturated FA concentrations, which were lower in eggs from LBC hens. Seasonal differences on the n-6/n-3 ratio were also observed for LBC with ratio being lowest during winter. (Chatzidimitriou et al., in prep)

WP5.1 multi-criteria impact assessment

Overall, the project demonstrated the potential of genetic selection methods, coupled with innovative production and management systems, to improve productivity and functional traits of dairy cows, pigs, sheep, and laying hens in the low input and organic sectors. This has been shown to generate significant environmental, welfare and health benefits, while improving the product quality and economic attractiveness of the low input and organic sectors. Furthermore, certain local and traditional breeds have been singled out as being particularly suited to genomic improvement under low input and organic conditions. While the efficiency gap between conventional and organic/low input systems has been reduced, significant challenges remain, concerning access to breeding infrastructure, mortality rates and resistance to diseases or overall economic benefit among others. Project data are still under analysis and therefore, for specific areas such as the role of different feeding systems on growth rate, conclusions are not yet drawn or remain preliminary. Uncertainty aspects have also been addressed, whether they depend on lack of sufficient data or on the inherent complexity of the breeding and management systems.

Dairy Cattle. The main project innovations for dairy cows relate to improvements in scientific methodology on estimating genomic breeding values, particularly genetic evaluation for health traits (incidence of mastitis etc). The assessment of environmental impact shows the possibility to reduce methane emissions using genomic breeding programs and the potential of genetic selection to improve functional traits even in smaller populations of local breeds. Welfare, health and quality assessments suggest genomic selection could be successfully applied to improve functional and productivity traits. On the basis of current results (assessment and use of new functional traits for genetic selection), other production systems could be included in future analysis. A study on the impact of different feeding system on the quality of milk and cheese, and interaction with breed, was also conducted. Economic assessment indicates the potential financial benefit of implementing genomic selection in the Brown Swiss cow population, by reducing breeding costs. Results suggest genetic selection can improve productivity and functional traits and therefore provide environmental, health, product quality and economic benefits, for both organic and low input systems. However preliminary results need to be corroborated by further research. Uncertainty and ethical implications also need to be better addressed. "First results indicate that it is possible to derive genomic breeding values that are more reliable than conventional breeding values for most of these traits. This provides a good basis for early selection, so that it will be possible to obtain more genetic progress in these functional traits which are especially relevant for the low input sector." (Simianer et al. 2013).

Pigs. The main project innovations for pigs concern the analysis of effects of different breeds and feed options on product quality, together with a complete economic valuation (growth, mortality, feed efficiency, costs). This was done for conventional breeds (selected to suit more intensive systems) as well as some traditional/local breeds. The assessment of environmental impact indicates the possible contribution to landscape preservation and other environmental benefits through genetic gain in traditional and local breeds, leading to improved growth rate and feed conversion in old breeds by crossbreeding. The economic assessment focused on a comprehensive evaluation of a range of genotypes and feeds on product quality (comparing economic efficiency of different breeding systems in organic and LI systems). Overall, the multi-criteria assessment indicates the potential of genetic selection and cross-breeding to improve the welfare, environmental impact, product quality and economic potential of traditional and local breeds.

Sheep. For sheep, the main project innovations relate the impact of pasture management on lamb performance, quality and shelf life of meat, as well as perseveration of good health and high reproductive performance of dairy ewes. For instance, mountain grazing for at least 2 months/year in summer was shown to reduce infection with internal parasites. Assessment the environmental impact indicates the possibility to reduce methane emissions using forages containing condensed tannins and reducing age at slaughter, as well as lowering non-renewable energy inputs, through better use of forages, primarily grazing, high feed self-sufficiency and limited use of mineral nitrogen. The welfare,

health and quality assessments indicate the high potential of adaptive breeding to improve breeds suitable for low input and organic systems. Also, animals in extensive systems have less subclinical mastitis and almost no parasitic infections. The project has investigated in-depth the impact of different feed systems on meat and milk quality. The economic assessment demonstrates the potential of improving product quality and image, for low input and organic systems, through less input and thus lower synthetic components, environmental impact and a stronger local identity. However, the challenge is to maintain productivity with lower inputs together with increased rusticity; requiring assessments in different breeding contexts. Overall, evaluation shows the importance of feeding on environmental impact, animal welfare, meat and milk quality. Although adaptive breeding can go a long way towards improving efficiency in low input and organic systems, economic challenges remain, mainly related to productivity.

Laying Hens. Assessing the environmental impact for poultry shows, due to new technologies and production systems, the efficiency gap between conventional and organic/LI is narrowing in terms of emissions, energy, land use or global warming potential. Welfare, health and quality assessment indicate significant progress on management to improve chicken welfare and reduce mortality (for instance due to feather pecking or infectious diseases). Ethical aspects such as the raising of cockerels are also tackled. Economic assessment also suggests the performance gap between organic and free range on the one hand and conventional production on the other, is closing, with positive impacts on the efficiency and sustainability of production. The increased performance of free range and organic farms can have a positive effect on profit margins, with multi-tiered free range and organic systems appearing as the most economically attractive. However, the impacts are still difficult to quantify due to insufficient data.

WP5.2: Ethical impact assessment

The project description (LowInputBreeds 2009) originally envisaged the ethics workshops of WP 5.2 as impact assessments, that is, ethical assessment of the impact of the research. Certain ethical issues were mentioned initially as potential objects of assessment, however, the first workshop led to a change in perspective. For one thing, moderators engaged by WP 5.2 could not detect research impacts that might involve serious ethical issues. Perhaps the closest was discussion about genomic selection for dairy cows in SP1, although, on closer inspection, even this turned out not to involve serious ethical disagreements, but rather different opinions about future strategies for breeding in organic dairy cows. Rather, researchers presented a number of challenges for low input animal production which they perceived important, and to some extent, as researchers working to the benefit of low input agriculture, also saw as challenges for themselves. Hence, the perception of these challenges became the focus of the ethics workshops.

Observations from the First Symposium. What have low input production systems got in common? If we look at the LowInputBreeds project, dairy cow and sheep systems are based, at least partly, on grassland grazing. This is not the case for pigs and laying hens, where the food mostly is provided. However, for the sake of the animals, they are allowed freedom of movement, and much of the time they are kept outdoors or at least given access to outdoor areas. An overall unifying aspect of low input production thus seems to be loosening the restraint of animals.

The various forms of 'low input' animal production sets itself apart from so-called conventional, intensive animal production in various ways and to various degrees. In an influential early conceptualization of intensification, the Brambell Committee identified "as the chief characteristic of intensification; the rejection of traditional outdoor foraging systems in favour of bringing the food to the stock, housed permanently indoors, often with complete independence of season and weather conditions by the use of artificially controlled temperature, humidity and lightning". Under these circumstances, the primary objective of the farmer is to obtain the most efficient conversion rates on feed.

Two more characteristics are worth pointing out. The first is the independence of geography and seasons, of particular landscape and weather conditions, local grasslands and local restrictions on disposal of manure. The other is the strong restraint on the animals. This is beneficial in terms of control,

e.g. protection from extremes of climate, predators, pathogens and diseases etc., but clearly it does not leave the animals much room for freedom of movement, not to speak of performing their natural behaviours.

It seems clear that a system that deviates from the full potential of intensification will meet economic challenges, because feed conversion efficiency will be compromised. This challenge is clearly visible for all four species groups. To some extent, competition from conventional production is met by low input production with increased intensification. This is perhaps most obvious in breeding, where high yielding (sometimes very specialized) breeds are used also in low input production systems. However, the consequences of these animals being more challenged in various low input environments, are clearly visible across all four species groups.

Because low input animal production systems brand themselves by their own value based choice of standards, particularly concerning how to manage them, they also raise higher expectations among consumers, not least among the more dedicated and loyal segments who buy the largest share of the products. This again makes low input production more vulnerable in case of problems.

For the general public, freedom of movement is perceived as a huge advantage for animal welfare, compared with restrictions placed movement and the lack of access to pasture in intensive animal production, hence an overall positive perception of low input production systems. The question that remains unanswered is to which extent this positive perception is sufficiently strong to outweigh persistent welfare challenges for low input production if they come to be more widely known?

Observations from Final Symposium. The follow-up workshop in Newcastle was arranged around the question of how each SP, in the light of the research results obtained during the project, perceived the issue of striking the balance between breeding for productivity versus functional traits of importance for animals' adaptation to specific environments.

It is striking that researchers perceive both challenges and solutions for low input production as something of a continuum with the development of conventional intensive production (only sheep appear to represent a more diverse picture). This is perhaps not surprising. Low input and intensive production both share the aim of increasing productivity, and a breeding history with productivity in focus. Solutions to the specific challenges are therefore also found by leaning on developments in intensive production and trying to adapt them intelligently to local and variable environments.

To see the problems in a continuum seems to make good sense from a biological perspective. However, the consumer perspective is almost missing in the researchers' perceptions yet some consumers are likely to expect a qualitative difference between the systems. LowInputBreeds was designed to meet the special needs of low input production; the project description raised the worry that if these need were not better met, consumers might lose confidence, which again would undermine the often necessary price premiums for products from these systems.

From the biological perspective, the project has showed a variety of possible ways to better meet the needs of low input production, however, these solutions also underline that low input production to a large extent shares both problems and solutions with intensive production. The question is therefore if these solutions will meet consumer concerns.

Since one of the defining differences is that low input systems explicit emphasizes care for animal welfare, and consumers are likely to put great weight on this priority, the answer will in our mind depend largely on whether or not the general public is able to – now and in the future – perceive a genuine welfare gain in these systems.

Dissemination and expected impact

The expectation for the project was to make a significant contribution towards the main impact from topic KBBE-2007-1-3-07: to: *“stimulate organic and ‘low-input’ livestock production by enabling logical, regionally-adapted breeding strategies to be developed that are compatible with sustainable production, high product quality and organic principles”*. This has been achieved in a number of respects.

Impact as seen by industrial partners

Dairy cattle sector:

The industrial partners Braunvieh Schweiz (formerly called Swiss Brown Cattle Breeders' Federation, SBZV) and Swissgenetics were involved in the project, when genomic selection (GS) became a hot topic in cattle breeding in 2007. In theory – yet proven at that time - GS is a promising tool to improve not only performance, but also functional traits. In Switzerland, many farms produce to organic standards, and low input systems are generally wide spread.

Of the results industrial partners learned among other points:

1. GS really can help to evolve novel traits, but success depends on the trait complex; more promising results were achieved with conformation than with fertility traits, explained by the lower heritability of the latter.
2. A good phenotype recording scheme is essential.
3. Which new traits are accessible for routine evaluation now depends mostly on their economic importance and genetic correlations to existing traits.
4. Only recording a subpopulation and genotyping only cows is feasible, but 1000 cows are not enough to progress with new traits of low heritability. The cow subpopulation must be selected carefully reflecting the whole population structure and relationships.
5. GS can be applied to natural service systems.

The genomic relationship matrix G is much more informative than traditional relationship matrix A , hence gives a better tool to control inbreeding and maintain genetic diversity.

LowInputBreeds project has given us a considerable number of Braunvieh cattle (mainly cows) genotyped with a high-density SNP panel. Although this increases the reference data set, reliability of routine genomic breeding values has not increase substantially. But the high-density genotypes, mainly from cows, increase the accuracy in the routine imputation procedure. In the context of LowInputBreeds, we learned to handle high-density genotypes and to implement novel functional traits using GS. A major benefit also resulted from collaboration with project partners: valuable knowledge and new ideas were exchanged.

As a conclusion, the Swiss cattle breeding industry can profit out of the LowInputBreeds project manifold, mainly due to the gain of knowledge and experiences.

Sheep sector

Sheep breeding is mainly in the hands of farmers, especially in Mediterranean and alpine regions involved in the sheep subproject, making integration of approaches and acceptance by the industry relatively easy for all involved in the sheep SP. In addition the Greek partner DEMETER and collaborators, identified points to improve communication with the farming communities based on the following rules:

- “Motivation to change”: Basic marketing theory says that a change of practice by a “target” is usually motivated by having to satisfy a need.
- “Invisible pain”: In our case, gastrointestinal parasite infections and subclinical mastitis are difficult to “visualise” since the “problem” is mainly production losses which makes adoption in such programs complicated.

- “Innovators are brave but rare” Awareness and knowledge alone do not guarantee adoption; many other factors also affecting decision making and experimenting with new ideas can risk being regarded as a social maverick. This may cause resistance to adoption, as can incompatibilities with existing culture, technology, business or personal objectives.
- “I don’t have time!” It is understandable that farmers prefer less complex solutions given the increasing load on existing farm labour, a declining population of willing workers, and increasing demands on intellectual and financial resources.
- “Who and what do I believe?” Farmers receive and seek advice from various sources in the private and public sectors, and their influence should not be discounted in an extension program.
- “I don’t like reading” We need to provide simple, prescriptive and short messages. Farmers use a range of information sources and are far from a homogenous or static population. Levels of literacy, age and willingness to change along with reliable access to the internet, influence the preferences when seeking out information.
- “Last time I was told...” Experts and advisers may lose credibility because of previous poorly understood unsuccessful messages; when reasons are credible and well communicated, this may be ameliorated.

Overall, coming to the end of the project, we are happy to say that we achieved a very challenging target from which both ends had a significant gain. Most participating farmers complain the study ended and they will be happy to participate in such studies in the future.

Pig sector:

The globally active pig breeding organisation TOPIGS based in the Netherlands was the industrial partner in the pig subproject. In The Netherlands, approximately 60 organic pig production herds exist, with a total of around 5,000 sows. Prior to LowInputBreeds, most of these replaced breeding stock by purchasing gilts from conventional pig breeding herds, which had obvious limitations. Sow replacement rates on Dutch organic herds often average more than 30% of the herd, whereas EU regulations on organic livestock farming (2092/91) require that replacement rates from conventional origin do not exceed 20% of present stock on an annual basis, there was a clear need for alternative breeding strategies. A combined approach of modelling studies and discussions with Dutch organic herdsmen resulted in the design of TOPIGS EkoFok: a breeding structure tailored to the wishes of the organic pig producers. In TOPIGS EkoFok, the best sows in the herd are selected as mother of the next generation of gilts and the breed of boar is changed (rotated) each generation. This so-called rotation breeding allows small herds to exploit crossbreeding in a fully self-contained and sustainable manner. TOPIGS EkoFok is an example of a 'closed' system with on-farm sow replacement: the herd remains closed and only boar semen needs to be purchased for production of replacement gilts or slaughter pigs. Breeding stock originates from the conventional TOPIGS breeding program, but replacement gilts are selected in an organic environment which gives advantages in terms of environment-specific adaptation. Furthermore, TOPIGS dam line boars that are used to produce replacement gilts are ranked according to a specially developed breeding index where more emphasis is given to traits important for organic production, such as piglet survival and mothering ability. Currently, around 50% of the Dutch organic pig herds are using TOPIGS EkoFok with Yorkshire and Landrace sow lines with the highest genetic merit for desirable traits (e.g. mothering ability, piglet vitality, sow longevity) for organic pig production.

Laying hen sector:

Institut de Sélection Animale (ISA), the layer breeding division of Hendrix Genetics, was the industrial partner in the poultry subproject. In poultry the majority of organic eggs come from relatively intensive farms, that purchase almost all feed required. For organic production it is clear that providing the right quality of feeds (protein) is a problem, even more so when organic diets have to be composed out of 100 % regionally sourced (from the EU) organic ingredients. If rules for organic diets become tighter it might

be necessary to reconsider genotypes that can deal with such diets, or adapt the rules for organic production. This will imply a more pronounced difference between organic and free-range production.

The necessity for beak treatment is an important issue in the EU. The results from the project show variability between flocks in mortality, feather and body condition of hens are wide, although the relationship of these parameters to beak treatment is rather weak. All organic flocks and all flocks in Switzerland have intact beaks, while mortality, feather and body condition are on average not worse than among beak treated free range flocks in The Netherlands.

It is possible to expand the period of lay from the current 70 weeks to 80-90 weeks without moulting and to > 100 weeks with moulting. This reduces replacement rates and hence the number of cockerels born per unit of eggs produced. Raising of cockerels for meat is technically no problem - marketing them is. It is questionable if more than a niche market for cockerels or dual purpose breeds can be developed. Nevertheless the breeding company involved in the project decided to develop a dual purpose breed for this niche market.

Egg quality, both sensory and nutritive value parameters does vary although differences between production systems and/or genotypes are minor and unlikely to impact on human nutrition.

Management programmes and greater transparency on performance of laying hens among farmers facilitate compiling and sharing of information, illustrated by the success of the workshops and farm visits initiated in LowInputBreeds . Partners in the egg production chain have become more active in sharing information acting as respected learning networks.

The breeding companies now put more emphasis on longevity and social behaviour of hens in their programs and more progress can be expected. Due to the changes in the performance of current genotypes, the need to develop specific lines for organic and free range systems is reduced.

Dissemination activities

A wide range of dissemination activities have been carried out through-out the life of the project, targeting primary producers (across all species), consumers and fellow scientists

Exploitation of results

The participatory nature of research in LowInputBreeds facilitated dissemination and outreach activities and hence, potential impact of our findings. Farmers of all species were actively involved in planning and implementing much of the work, actively seeking the overview of our findings. Hopefully LowInputBreeds identified scope to improve efficiency in low-input and organic production systems as well as enhance animal product quality with respect to consumers' health. Management and breeding approaches to enhance milk, meat and egg quality were identified, with many offering an insight into control of saturated fatty acid content of animal derived foods.

Production efficiency will be enhanced by the identification of:

- genomic breeding values for functional traits in Brown Swiss dairy cattle
- sustainable crossbreeding strategies for dairy cows
- rapid genetic progress if selecting AI bulls by genomics
- scope to select rustic milking sheep breeds for reduced stress
- feeding and grazing management to improve lamb performance
- an appropriate breeding strategy for organic pigs
- appropriate breeds suited to 'commodity' and 'niche' organic pork products
- the importance of sows' rearing environment, in addition to their genetics, to control early piglet mortality

- important attributes for hens kept under free-range or organic production
- the scope to extend egg laying, reducing the need for replacements hens and associated destruction of male chicks and spent hens and costly rearing of pullets

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