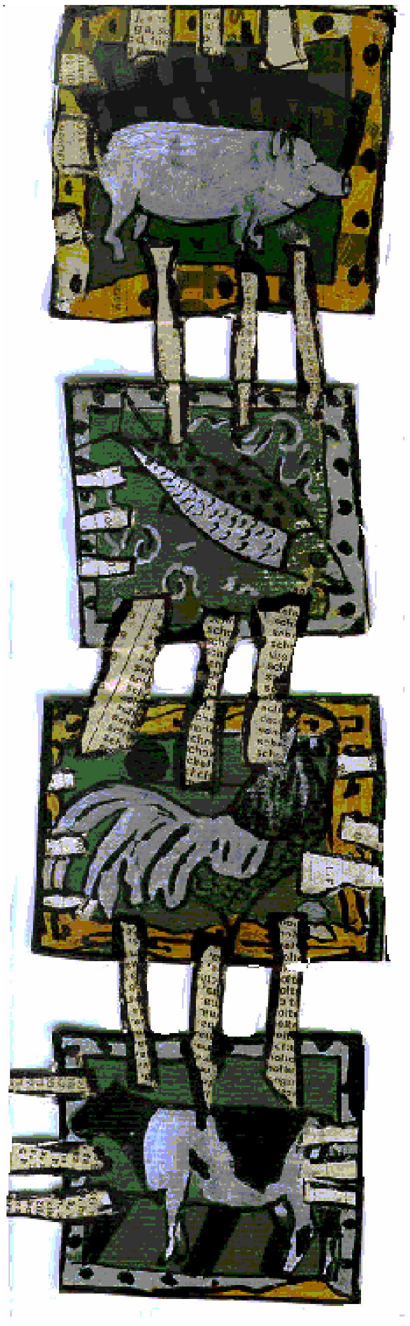
Farm Animal Industrial Platform *(FAIP)*



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The Reproduction and Selection of Farm Animals

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The Reproduction and Selection of Farm Animals

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Farm animal industry is on the threshold of the application of new biotechnologies in farm animal reproduction and selection. The developments in breeding and livestock production have resulted in the farm animals of today producing high quality products at relatively low cost. Both the new technologies and the traditional breeding of farm animals may raise questions that involve society. Milk, meat, fish and eggs are an important part of our daily food consumption. Before a consumer buys a product, it has made its way through the food production chain, making the origin of the product and the way it is produced very distant. However, consumers influence livestock production directly with their purchases. Farmers produce the food that will be bought by consumers. Breeders breed the animals that will be used by the farmers. The aim of this article is to make farm animal breeding and its role in animal food production more transparent. To achieve this, the European reproduction and selection industries of cattle and other ruminants, pigs, poultry and farmed fish, represented in the Farm Animal Industrial Platform *(FAIP)*, have jointly made an overview of the history and state of the art in breeding (Farm Animal Industrial Platform, 1999) and of the factors that will affect the development of farm animal breeding. Furthermore, possible future models of farm animal reproduction and selection have been worked out. These models are meant to be the subjects for discussion on the possible and desired developments in farm animal breeding.

The contribution of farm breeding to food production.

The breeding of farm animals takes place at the beginning of the food chain. From consumer purchases it is a long road from the retailer to the processor, to the farmer and finally to the animal breeder. Animal production takes place on farms where farmers fit both the market's and the consumer needs by choosing with great care replacement animals for their own production. In this way farmers gradually bring the population characteristics in the direction of the consumer needs. This is called *genetic improvement*. The role of animal breeders and breeding companies is to produce and disseminate improved animals to the farmers.

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Breeding farm animals takes place in three steps. A breeding goal is determined. The animals that answer best to the breeding goal are identified and selected. Then, they are reproduced and disseminated to the farmer.

Definition of the characteristics to improve (breeding goal). In general, farm animal populations do not have all the desired characteristics. The first step in a selection programme is the definition of a breeding goal. This is a description of the qualities an animal should ideally have in certain circumstances or, in other terms, the definition of the characteristics to improve. Different markets and different farming systems may need different animals and consequently different traits need to be improved to achieve the breeding objective. Most of the time the breeding objective involves more than one trait, for example laying hens should produce more eggs with better shell quality, lay longer and have stronger legs. When more than one trait is included in the selection programme it must be decided for each trait how important it is compared to the others. One should also bear in mind that improvement for a trait may influence positively or negatively other traits.

Moreover a breeding goal must be determined a long time in advance. Depending on the species, (i.e. the biology of the animal and the characteristics of the population), on the tools available to realise the desired improvement, and on the number and the characteristics of traits one wants to bring nearer to the goal, it takes three, five, ten years or more to achieve appreciable results. The definition of a breeding goal is then a long term prediction of the consumer and of the market needs. Besides that the breeding goal may change in time, one should be aware that the decided breeding goal will influence the management of animals, and consumer appreciation for a relatively long period.

Identification and selection of superior animals. To achieve improvement for the characteristics in the breeding goal, animals must be identified, and a value (selection index) given to each animal indicating their ability to improve the desired characteristics. Those animals fitting the breeding goal best are preferred when producing the next generation. This is called “selection”. The performance of an animal (phenotype) is a mixture of its genetic make up (genotype) and of the environment. Animals are selected according to their phenotype (mass selection), estimated genotype (index selection) or measured genotype (Marker Assisted Selection). Only heritable traits can be selected for.

An animal does not necessarily have to express the trait one wants to select for. This is the case for sex limited traits like milk production. Males can carry excellent genes for milk production and one can measure the genetic value through the daughters or directly in the genes of the animal itself.

Furthermore in poultry and pigs, dam and sire lines are selected separately for reproduction traits and for production traits. These lines are then crossed to achieve the benefits of both, and to benefit from heterosis in the form of vitality and production. Heterosis is the improved performance of offspring gained by crossing unrelated populations.

Reproduction. Reproduction is simply the ability of an animal to produce offspring. This is not always an easy process, e.g. zoos sometimes have to try hard to get some of the animals reproduce. Farmers and breeding organisations are involved in various phases of the reproductive process such as identification of optimum time of insemination, health status of the reproductive organs, semen production and conservation, embryo transfer and ovum pick up.
Control of reproduction enables a more optimal distribution of breeding stock to distant farmers. It also is an important tool in disease prevention. A certified artificial insemination station does not spread disease as easily as a natural mating male going from farm to farm. Furthermore, semen and embryo conservation can be important tools in the conservation of biodiversity.

The size of the farm animal reproduction and selection sector is small. Despite this, its impact on livestock production is high because genetic improvement is permanent (improvements are genetically determined), cumulative (every effort is built upon the improvement reached in the previous generation), and disseminated widely through the production chain. For that reason a discussion about farm animal breeding and breeding developments is a discussion about the kind of animals that are or will be used in livestock production.

History and state of the art in farm animal breeding

Today's farm animal breeds originate from a few wild species. The domestication of most of the farm animals took place millennia ago (Zeuner, 1963). At first, only animals which were easy to handle, easy to reproduce and which survived the winter period were actually used for breeding, thus domesticating the animal. It took until the 19th century before the first official herd books and breed societies appeared in cattle, sheep and pigs. They registered family records and/or production information. Early selection procedures were based on individual performance only. Later, selection was carried out by using family information to determine differences between non-heritable management and heritable animal effects on the performance of an individual animal (Van Vleck, 1993). Own performance and family information were combined in indexes enabling the selection of top animals, best fitted for the breeding goal. Improved availability of computers and improved statistical methods allow much more accuracy and allow more traits to be included in the selection index.
In poultry, extensive family records are kept of the low heritable reproductive traits such as egg numbers, egg size and hatchability. For growth and conformation characteristics, which are more highly heritable, the techniques in poultry breeding are based on mass selection on phenotypic characteristics. Poultry and pig breeding programmes work with several unrelated lines to select for a number of traits, in the end crossing these (two or three) breeds for the extra vitality and performance of the heterosis effect.
Although fish farming has been practised for more than 4000 years, fish breeding programmes are still at the initial phase, and in some breeds no selection takes place. Most of the genetic improvement in fish is based on mass selection without pedigree information. In several countries selection programmes incorporating genetic information are in place, enabling selection for several traits or traits that need to

be collected from families (quality traits, disease resistance). Fish hybridise naturally in the wild (carps, salmonids, sturgeons). Hybrid fish can be created by farmers, e.g. fish resistant to certain diseases. Oysters and molluscs are mainly coming from wild spats collected form natural spawns. Hatcheries use wild breeders without a breeding programme.

Recently, the first DNA tests in farm animals to detect genetic defects have been developed (Lenstra, 1999). The best known single gene is the one for stress susceptibility in pigs, causing sudden death if the animal is stressed (Ollivier *et al.*, 1975). A DNA test is available to detect this defective allele and to avoid the use of animals carrying it as reproducers.

The breeding goal of farm animals has changed over the years. Many cattle breeds were originally dual purpose, used for milk and meat production and occasionally draught purposes. Even now a lot of breeds are dual purpose breeds, combining relatively high milk production with good meat production thus providing significant extra revenue for the farmers. Beef recording and specialisation into beef breeds has mainly developed in the last 40 years – starting in the 1960s with weight recording on farm, later followed by performance testing in test stations allowing direct comparison of animals. Breeding goals in pigs in the early 1900s was also dual purpose (litter size and growth) and based on phenotype. Pig breeding was almost entirely pure breeding until 1960. In the late 1980s, improved computing technologies and statistical methods allowed to select for traits with a low heritability, followed by further specialisation into sire and dam lines. Before the 2nd World War all poultry breeds were dual purpose as well. The females would be used for table egg production and the males were grown for meat consumption. Other species of poultry such as turkeys and ducks had no organised breeding programme. After 1945, in the USA, breeding programmes were developed, with specialised lines and breeds for table egg chicken (layers) and meat chicken (broilers) instead of dual purpose chicken. At a later date, also breeding programmes for turkeys and ducks emerged.

Furthermore, the possibility of incorporating more traits into selection programmes did change the breeding goal from purely aiming at production towards the incorporation of health, reproduction and behavioural characteristics. There are differences in Europe between the breeding goals of companies and between regions. For instance Scandinavian countries have routinely recorded health and functional traits like mastitis and fertility in their system. Some poultry firms, starting from having only production characteristics like carcass quality in the breeding goal, have moved towards incorporating taste and health, and later also welfare in the breeding goals as well.

In cattle, artificial insemination is used in most of the cases. Non-surgical embryo transplantation is possible, but is mainly used for highly valuable animals because it is a relatively costly procedure. In goats and sheep artificial insemination is not common practice, because semen cannot be frozen easily and fertility, after thawing and insemination, is still not acceptable (Barillet, 1997). The reproduction period of sheep and goats is usually seasonal. Oestrus synchronisation is practised occasionally. The exchange of genetic material in pigs is mainly by fresh semen, since frozen semen technology in pigs is still underdeveloped (Meredith, 1995). Non surgical embryo transfer might be available for commercial use in one or two years. In poultry breeding, mainly artificial insemination is used nowadays (Surai & Wishart, 1996). Eggs can be transported world wide, thus enabling the use of breeding eggs from the

USA or Europe in e.g. the Far East. In most fish, the season of spawning can be managed with control of e.g. light or thermo-period. Most fish species ovulate or give semen by gently stripping of the flanks. In marine species hormonal synchronisation is the only possibility to get ova and semen. Freezing semen is possible, but mainly practised for conservation purposes. Embryonic eggs can be transported, and disinfected to prevent disease risks.

A more detailed description of breeding technologies and developments in research is provided in Appendix 1.

Factors influencing the future of farm animal breeding

An exercise is made to determine which factors most probably will influence and determine the farm animal breeding of tomorrow in Europe. The implication of consumers, legal climate and bio ethics on breeding will be worked out by the other partners. The main scientific, technological, and economical factors are described below.

Sustainability. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987). Sustainable agriculture aims at production systems that can provide man with food in a balanced way. European animal production is characterised by no use of additional hormones nor growth promoters. Many by-products from human food industry (e.g. soybean and citrus extractions) find their way in animal feed. A lot of farms are family farms, and they play an active part in the maintenance of their local rural environment. Compared with other continents, in Europe there is more concern about animal welfare and sustainable production. Breeding can be directed towards animals having the ability to digest by-products in a better way, to use feed more efficiently, or to produce in extensive environments. The art will be to find the right balance between animal production, animal welfare, environment, product quality and consumer price.

Structure of farms. The size of farms is expected to grow continuously. In the first place the profit per animal decreases year after year. Consumer prices tend to get lower. Production costs increase. The result will be increased production per hectare, per litter, per animal. Also automation, hygiene regulations and a controlled food chain may force small farmers to give up business, because the investments needed are too high. On the other hand, high quota prices (Europe, Canada) keep farm sizes from expanding. European (cattle) farmers, but also Canadian poultry and dairy farmers currently protected by import barriers and subsidies, will have to adapt to world market prices. Farms where the farmer lives near the farm will disappear more and more. In the USA farms with one million pigs or a hundred thousand beef cows already exist.

Exceptions will occur for farmers producing for niche markets or in a special production system (e.g. organic) who will be able to get a higher return per animal. However, with the increase of organic production prices tend to go down because of the power of the intermediates that buy and sell the products. More and more primary producers will have less control on the marketing of their products.

Global markets/international developments. A great deal of breeding knowledge and a number of international breeding companies are situated in Northern Europe and North America. Farm animal breeding will globalise more in the future, especially in cattle and pigs, while poultry breeding is already organised globally. The push for borderless organisation will not come from the scientific communities, but from breeding companies that need to stimulate the development of international genetic programmes in order to finance the necessary investments in software development (Lohuis, 1999) and DNA technology.

Structure of animal breeding. The structure of breeding companies differs between species, mainly due to the biology of the species. In ruminants there is mainly an open structure, in which a proportion of the day to day producing female animals can become future breeding animals. Dairy bulls are even compared world-wide by the International Bull Evaluation Board (INTERBULL) and frozen bull semen is traded globally. In poultry all the breeding work can be done in house and a few companies can and do provide the world with breeding stock. Pig breeding is in an intermediate situation. In aquaculture breeding is at the very start of developments, but in a few decennia a few breeding companies may provide the world with breeding fish. In the future cattle breeding companies may merge to form fewer world-wide operating companies, providing farmers with semen and embryos. Furthermore, in cattle breeding nucleus herds, and maybe hybrid lines, will become part of the picture. The number of pig and poultry breeding companies may reduce further and their size increase. Alongside that there may be smaller companies serving niche markets in cattle, pig, poultry and aquaculture breeding.

Computing and handling data. Handling information is very important in animal breeding. More sophisticated hardware and software will improve these possibilities. 'On farm data' can be sent electronically to any estimation company . The improved computing capacity makes it possible to analyse all these data together. For example pig breeding companies will increase involvement of the farmers by using on-farm data for the genetic evaluation and reproductive management of breeding animals. Specially designed or adapted breeding programmes can prevent small breeds from having too much inbreeding and at the same time the maximum genetic improvement (Gandini & Oldenbroek, 1999; Meuwissen, 1999).

Biotechnologies. New technologies are DNA technologies from Marker Assisted Selection to transgenesis, and reproduction technologies like gamete sexing, embryotechnologies or cloning. Some DNA tests or embryotechnology in cattle are already applied. Others are under research and could be used in the near or more distant future. Marker Assisted Selection could be used to detect genes for genetic disorders (Hoeschele & Meinert, 1990; Georges *et al.*, 1993), disease resistance, product quality (Andersson *et al.*, 1994; Georges *et al.*, 1995; Ashwell *et al.*, 1997) or other traits of interest. Transgenic animals would have a special feature, e.g. in New Zealand there are plans to set up a flock of genetically alternative cows producing milk that is similar to human breast milk. Cloned animals could be used to determine the genetic component of important traits, or to disseminate valuable production animals from top breeding population to production populations more quickly. Technologies can only be applied if their use is economically viable. Furthermore, the question is whether public opinion and consumer purchases would favour the application of new technologies.

The development of new technologies and the high cost involved in research, may force the market players legally to protect their research efforts by means of patents or to use trademarks in order to get a return for the research efforts. The possibility of their legal protection may introduce exclusive rights for certain applications and thus influence the structure of breeding and the technologies applied by the several market players. Furthermore, the need to fund research that is too expensive for one market player may stimulate companies to become partners in research or to amalgate their companies.

Biodiversity. Breeding companies rely, for their selection possibilities, on the genetic diversity that is available in the species/the populations they work with. It is only possible to select for a certain trait, if the animals you select from show variation for this trait. Breeding companies carefully take care of the variation within their breeding stock. It is part of their breeding policy to maintain the available genetic variation, to maintain a 'zoo of special animals or species' and to keep an eye on the extremes of the genetic horizon. However, the genetic make-up of the breeding animals is not known, only estimated by means of performance measurements of the animals and their relatives. In general, information is available about traits that are taken into consideration. Although more traits are incorporated in the breeding goal than a few decennia ago, there can be genes or gene combinations for traits that are presently unimportant or that we are not aware of yet. Loss of genetic material can take place invisibly, as the role and exchange of genetic material between populations, selection and crossing take place gradually. For instance, it is not known what exactly is the definition of European lines and breeds, e.g. German and Dutch Landrace. Knowledge about their real genetic distance (Nei, 1987; Eding & Laval, 1999) and relationships is insufficient. Research on the consequences of 'invisible loss' through genetic drift, selection or crossing could give a better picture of this.

Breeding often concentrates on a few breeds per species. Also, 'popular' breeds like the Holstein Friesian cattle get mixed with local breeds world wide. The consequences for biodiversity of farm animals need further consideration (Farm Animal Industrial Platform, 1998).

Animal genetic improvement and conservation of genetic diversity need and use the same tools and technologies (data analysis, reproductive technologies). Co-ordination at the European level of efforts undertaken in different countries is necessary.

Future models of farm animal production systems

Global market, technological, biotechnological, animal welfare, management, political, economical, legal and societal developments may force animal production systems to change. In order to be able to consider new evolutions with care, and to have future pathways for discussion, three models are worked out in this section.

Partly they represent an extrapolation of today’s reality into the future as, currently, diversification of breeding is already part of the reality in Europe. Different organisations, different countries or different farming systems work with their own breeding goals. Several models can be applied in one country or within one organisation, each serving part of the market. The drive behind the differentiation is historically determined, following market demands and/or motivation comes from pressure for animal welfare and other societal demands.

In the first model (*conventional path*) farm animal breeding and production develop further towards a system similar to the current one. There is no need to change the actual animal production system, mainly taking place at family farms.

In the second model (*alternative path*) the emphasis is on welfare, disease resistance, environment (pollution), niche markets, organic products, regional and special products. Consumers with differentiated demands for food and societal needs are the main drive behind this scenario.

The drive behind the third model (*low cost path*) is the demand of consumers for cheap and safe products in a global competitive market.

In all models the quality of products must be good. The first and third models are targeted on economic characteristics taking into account certain thresholds for e.g. mortality, welfare etc.

In general a breeding goal is determined by economic motives of farmers, mainly based on market and economy. Next to this, political or societal conditions may determine the breeding goal.

Animal breeding is associated with reproductive technologies, like Artificial Insemination (AI) and Embryo Technology (ET) and with DNA technologies, like Marker Assisted Selection (MAS). Although in principle newly developed techniques (Ovum Pick Up, cloning, transgenesis) could be used to achieve the different goals described in all models, their application may be less likely or would have to be adapted, in order to meet public demand or to reach the breeding goal faster in a specific model. Table 1 and Table 2 represent today's perception that traditional aspects and technologies will be used in the several models.

Table 1. Today's perception that traditional aspects may be used in the conventional, alternative or low cost path

Traditional aspects	**Conventional path**	**Alternative path**	**Low cost path**
Decrease production costs	++	+/-	++++
Increase uniformity in breeds/goals	+	---	++++
Balanced breeding	++	++++	+

++++ used routinely, +++ likely to be applied, ++ will probably be applied, + may be applied, +/- may (not) be applied, - not likely to be applied, -- very unlikely to be applied

Table 2. Today's perception whether technologies may be used in the conventional, alternative or low cost path

Technologies	**Conventional path**	**Alternative path**	**Low cost path**
Marker Assisted Selection	+++	+++	++++
Artificial Insemination and Embryo Technologies	+++	++	++++
Transgenesis	-	--	++
Monosexing (fish)	++	-	+++
Triploïdy (fish)	+	+++	++
Cloning	+/-	--	+++

++++ used routinely, +++ likely to be applied, ++ will probably be applied, + may be applied, +/- may (not) be applied, - not likely to be applied, -- very unlikely to be applied

1. Conventional path

In the actual production system, mainly taking place at family farms, the breeding goal aims at improved efficiency of animal production in order to provide consumers with high quality animal products (milk, eggs, meat) at a reasonable cost price. In the conventional path, more genetic information on functional traits would be considered in the breeding goal because of factors limiting increase of production, e.g. milk quotas, and the awareness that genetic improvement for high production efficiency may produce undesirable side effects (Rauw *et al.,* 1998). There would be more emphasis on quality traits and disease resistance, to increase food quality and food safety. International competition would be likely to favour those companies that provide breeding stock that will improve general animal efficiency and/or deliver improved products.

Technologies available today like Artificial Insemination, and Embryo Technologies would also be used in the management of populations in the conventional path. Developments in research would enable the use of Artificial Insemination routinely in all species and Embryo Technologies in all farmed mammals. The development and use of new biotechnologies would not be seen as a primary need to achieve more quickly breeding goals.

Description of conventional path in cattle, sheep, goats, pigs, poultry and aquaculture. As high producing cows may exhibit lower fertility, some metabolic disorders, and some health problems, the breeding goals in milk cattle would incorporate, next to milk production and body structure, issues related to health, metabolism, non productive traits, and longevity (Groen *et al.*, 1997). The quota system that does not allow farmers to increase their production, and thus stimulate more efficient and profitable production, would favour selection for traits other than production in order to decrease the costs of production and increase the farmers' income although production will remain the main selection criterium. DNA tests would be available to detect animals carrying genetically transmittable diseases or genes improving better milk quality, e.g. k-casein (Lenstra, 1999). The aim in beef cattle and meat sheep would be to produce more meat in less time, with the minimum amount of feed, and with the best possible reproductive rate. Characteristics considered in the breeding objective would be mainly growth, carcass, and reproductive traits. Traits like meat quality that are now only measurable on slaughtered animals would be measured on live animals due to improved technologies. The double muscle would be present in some beef breeds, although double muscle causes mainly caesarians in e.g. the Belgian Blue. (Hanset, 1996). DNA tests on the myostatine gene (beef) (Ott, 1990; Grobet *et al.,* 1997; Masabanda *et al.*, 1998) or the Callipyge gene (less fat and more muscles in meat sheep) (Cocket *et al.*, 1993) would assist further selection. Milk composition and milkability, udder traits, and prolificity could be included in the breeding goal of milk sheep and goats next to milk production traits.

In pigs, selection would be aimed at strong, efficient, and high producing animals. To achieve this, selection criteria would be further differentiated between males and females lines, to take advantage of extra productivity and vitality due to the heterosis effect. Special crosses would be developed for specific housing systems. Information of the individual farms would be used to decide which families within the population contain valuable genetic characteristics and which do not. DNA tests would be available to detect deviant alleles.

The selection of poultry for table eggs (layers) would mainly aim at larger numbers of eggs per hen housed, optimum egg weight, efficient feed conversion, and improved egg quality. Demand for eggs from non cage-systems would change the layers farming system, especially in Northern Europe.

In broilers, turkeys and ducks (poultry meat production) there would be continued selection for growth rate, feed conversion, eviscerated yield and breastmeat yield. The improvements in growth and yield characteristics would be achieved with increasing emphasis on quality and fitness traits through improved population structure, statistical methods and selection technologies. Examples of improved selection technologies include real-time X-ray technology to improve assessment of skeletal quality. Also other than production traits, e.g. skeletal quality, heart and lung function, disease resistance and other traits related to fitness or welfare would be incorporated in the breeding goal. Broiler breeding has used marker-assisted selection for many years in the form of serological determinants of resistance to Mareks Disease virus. Other markers could be used to improve disease resistance.

Currently selection in aquaculture has taken place for less than six generations in salmonids and two generations in marine species. No selection of breeders is recorded in molluscs. Breeding programmes would initiate selection for quality traits to decrease fat content in the muscle, improve yields at harvesting, and decrease the variation of the repartition of the lipids in the filet that causes variation of smoking success and the taste of smoke and salt. Furthermore, the development of lean strains could improve feed efficiency and decrease waste. This improvement could be extended to new lines and other species.

2. Alternative path

The production system, and consequently the breeding goal, would aim at moderate production levels, specific products (niche markets, organic products, regional products), health and welfare of the animals, environment and improved feed efficiency. The breeding goal would be towards balanced breeding, avoiding possible negative effects of breeding for production on other biological traits, e.g. mobility, reproduction, disease resistance. Not all technologies available today would be used to allow a product to be advertised and marketed with certain characteristics, e.g. organic products. Specific technologies or recently developed biotechnologies would be an exception. They could be used when there would be a strong need to reach a specific breeding objective. Examples could be the use of Embryo Transplantation and Embryo Sexing to ensure the survival and development of small and endangered breeds, the use of Artificial Insemination and Embryo Transfer, allowing the dissemination of genetic material free of diseases, or the use of Marker Assisted Selection to improve longevity, feather pecking, stress resistance, or a desired animal behaviour characteristic.

Three possible production systems are described:

a) **Animal Welfare** Non productive traits that can improve animal welfare would be emphasized in the breeding objective. Selection for increased production has also increased the danger that the homeostatic balance of animals gets affected. In a literature study Rauw *et al.* (1998) have presented over a 100 references of undesirable side effects of selection for high production efficiency for broilers, pigs and dairy cattle. High productive animals seem to be more at risk for behavioural, physiological and immunological problems. When selection and farming is aimed at higher production, the individual resources would be used mostly for production, and less for other demands, and the buffer capacity of the animals could be affected (Resource Allocation Theory, Beilharz *et al.*, 1993). Reducing emphasis on production would accelerate genetic improvement for non-productive functional traits. If the economic benefit of “welfare traits” does not overcome the decreased revenue due to limited improvement in production, consumers may be ready to pay for the animal welfare through the higher prices of products.

b) **Link region-breed-product / niche markets** Products of high quality and limited in quantity represent the typical production in different geographical areas. Usually these products are part of the local culture. Breeding objectives should be addressed to maintain breeds and production systems that guarantee the variety of local food (Gandini & Giacomelli, 1997). Associations between region of production and breed or particular product (cheese, meat) could increase the value of the production, especially in areas where intensive farming cannot take place. The farming system could be addressed to maintain a balance between production and environment, by subscribing a maximum amount of animals of a breed on a specific extension in order to produce a limited amount of product, guaranteeing a good price to the farmers. Moreover, the presence of farmers is important for land conservation in areas otherwise destined to be abandoned.

c) **Organic products** The demand for organic products is rising. The definition of organic products could lead to the application of particular breeding objectives. It will depend on the final EC regulation on organic production concerning what will be allowed or forbidden, and which technologies can be applied.

Description of alternative path in cattle, sheep, goats, pigs, poultry and aquaculture. Next to the selection criteria mentioned in the conventional path, other reasons would be brought forward to change breeding goals and to consider alternative traits on top of the production criterion. Traits, like longevity, calving ease, udder health, somatic cell counts, control of mastitis, fertility, would be weighted heavier in the breeding goals in dairy cattle than would be the case in conventional breeding. For example, instead of obtaining a genetic improvement of 100 kg a year for milk production with no benefit for other characteristics, one could decide to improve milk production only 50 kg and reduce in the meantime health problems and metabolic disorders. Another example comes from beef cattle. Here the selection criterion could be to avoid the use of animals carrying the double muscle characteristic as reproducers to increase calving ease. Furthermore, selection could be aimed at animals able to adapt to difficult environments and able to produce a live healthy new-born calf each year. Some examples of regional products, produced by local breeds are the Fontina from the Aosta Red Pie and the Reblochon cheese from the Abbondance breeds. Niche markets could request particular products, as is the case for the "Parmigiano Reggiano delle Vacche Rosse" made from the milk of the Reggiana cattle breed, today counting only 1000 head (51,000 in 1955). Multiple Ovulation and Embryo Transfer (MOET) could improve selection schemes in breeds limited in size but with an economic importance (niche markets) and help their maintenance and their survival.

In the alternative model for pigs wishes from society would be integrated in a rural production system with medium sized isolated family farms, evenly spread over the country, with high healthy animals. The breeding goal would aim at animal friendly production, possibility for display of natural behaviour, and residue free pork, incorporating traits like litter size, piglet survival, mothering abilities, ease of growing and lack of fat accretion. Farmers could combine these estimates in a personal index. In this way uniformity within a farm could increase, while at the same moment genetic variation between farms could be maintained. Import of new genetic material would be by means of semen or embryos because of the limitation of disease risk. There would be niche markets with local breeds or regional products (e.g. Iberian ham). Single gene technology could help to assess the presence of deleterious alleles, responsible for among others congenital disorders like atresia ani and tremor piglets.

Poultry breeders for table egg chicken (layers) would respond to customer preferences for eggs from non-cage systems in having a slower genetic progress for conventional traits and extra emphasis on behaviour traits and liveability in order to decrease the tendency towards feather pecking and/or cannibalism, and to minimise the incidence of floor eggs i.e. eggs not laid in a nest. There is some evidence that selection against undesirable behaviour could be effective. Breeding programmes could be developed for certain niche markets. The further development of the egg products market may require selection for the egg components.

Poultry meat breeding programmes (broilers, turkeys, ducks) would emphasise the quality and welfare of individual birds, skeletal quality, and improved heart and lung function, next to continued selection on meat production and feed efficiency. Although some progress has been made in improving disease

resistance, new technologies could accelerate this and make further improvements to bird welfare. Breeding programmes could be developed for certain niche markets, e.g. a particular type of broiler based on specific requirements such as colour, regional breed, organic production system etc. There is a growing niche market for Bronze and Black feathered turkeys. Slow growing turkey breeds with an increased subcutaneous fat content over the breast represent a market for traditional farmed Christmas turkeys.
In fishes and molluscs, the development of resistant strains could be one of the solutions to avoid diseases in open farming conditions, limiting the use of drugs and increasing product safety. Furthermore, specialised breeding lines would be developed for fish species not yet farmed (halibut, char, cod, sole, sparides, perch, catfish), in order to provide consumers with a high diversity of products. Some have potentially very high growth rates (thunnus, seriola). Others originate from other geographic areas in Japan, Chile, South America, Asia or Australia.

3. Low cost path

In the low cost path the goal would be to provide safe food at the lowest production costs. New methodologies to reach the objective of improved production efficiency would be explored and expensive research funded. Economic interest would be the pushing drive to use the most effective technologies available. Biotechnologies like cloning or transgenesis would most likely find their way here. Their application would mainly be related to ensure higher production at lower cost. This path is expected to be followed by producers at the global market: USA, South East Asia, South America, Canada, and maybe Europe. It can affect a large part of the food supply and may be of great interest to public opinion.

Description of low cost path in cattle, sheep, goats, pigs, poultry and aquaculture. In cattle, sheep and goats all breeding objectives would be aimed at reducing the cost of production. The cost/benefit ratio would determine which technologies and production systems could be used. Intensive farming would be the main instrument of production. In beef cattle there would be selection for double muscle. In sheep the Boorola gene to produce more offspring per delivery would be used.
In pig farming, family farms would gradually or rapidly be replaced by industrial farms, large well organised farms with very low labour input per animal. The selection for this environment would be on strong animals with a very good and adaptive digestive tract able to grow and farrow with little human intervention. Pig families with easy farrowing and good interaction between sow and piglets would be best adapted to this environment, even if litter size would be a little lower than usual in the conventional path. Uniformity in start of oestrus, in size of animals, in birth weight and quality of piglets etc. would be very important. A reduction in on farm variation would inevitably mean a reduction in genetic variation. Large farms grow large numbers of animals close together, causing increased disease risks. In large populations it is easier for pathogens to survive, making subdivisions within farms necessary or selection for animals with higher resistance.
The breeding goal for poultry table egg production (layers) would be for low cost safe production

systems, although the rates of progress for egg mass and feed conversion are expected to be lower in poultry, due to approaching biological limitations. Genes or genetic markers for desirable behavioural or disease resistance may be found and applied. When more cost-effective screening methods could be found, transgenic animals would also contribute to the genetic progress.
Genetic progress in poultry for meat production would be mainly aimed at growth rate, feed conversion, eviscerated yield and breastmeat yield in a cost-effective production system. Progress would be accelerated if marker genes or the trait genes themselves are identified. A better knowledge of Quantitative Trait Loci (QTL) affecting disease resistance would allow more accurate estimation of breeding values for such traits. Since pathogens evolve faster than the domesticated populations, it is vital that the new technologies do not narrow the genetic resource.
The genetic variability of all the traits in fish is 2 to 3 times higher than in the livestock species as fish species are still wild species. This means that an important potential of genetic progress exists. The benefit of the increase of the return rate of investment per kilogram produced and the decrease of the cost of raising would rapidly decrease the cost of the products. For example, Atlantic salmon cost have decreased from 12 US $ per kilo in the 1980s to 3 to 4 US $ per kilo in 1998. The part due to the genetic progress is still difficult to estimate as very few estimations have been published, but it could be expected that this cost would continue to decrease in the next decades. Furthermore, monosexing or triploïdy could be induced by external factors, e.g. temperature. Monosexing fish would allow fish of commercial size without hormonal treatment. Triploïdy, already present in the wild and giving sterile animals, would prevent selected fish from reproducing in the wild.

Discussion

This article has given an insight into the mechanisms and structure of breeding, in order to enable society to understand and direct livestock breeding and production. It has outlined which technological, economical and global factors will most probably influence the future of breeding and the animals used in livestock production. The future developments in production systems would differ according to species mainly because of biological differences. Nevertheless, many examples carried out previously for a particular case could be extended to different species or productions. For example feed conversion efficiency in all the species and production systems reduces the necessary amount of arable land.

The scenarios mentioned are model scenarios, meant to facilitate a discussion on the future of breeding. Differences between countries, farmers and breeding companies have resulted in a variety of breeding goals and practices. The conventional, alternative and low cost model can therefore also be seen as an extrapolation of today's reality into the future. The overall picture of future possibilities - moderate, alternative or just convenient for the consumer - gives an idea of the choices that can be made (Figure 1).

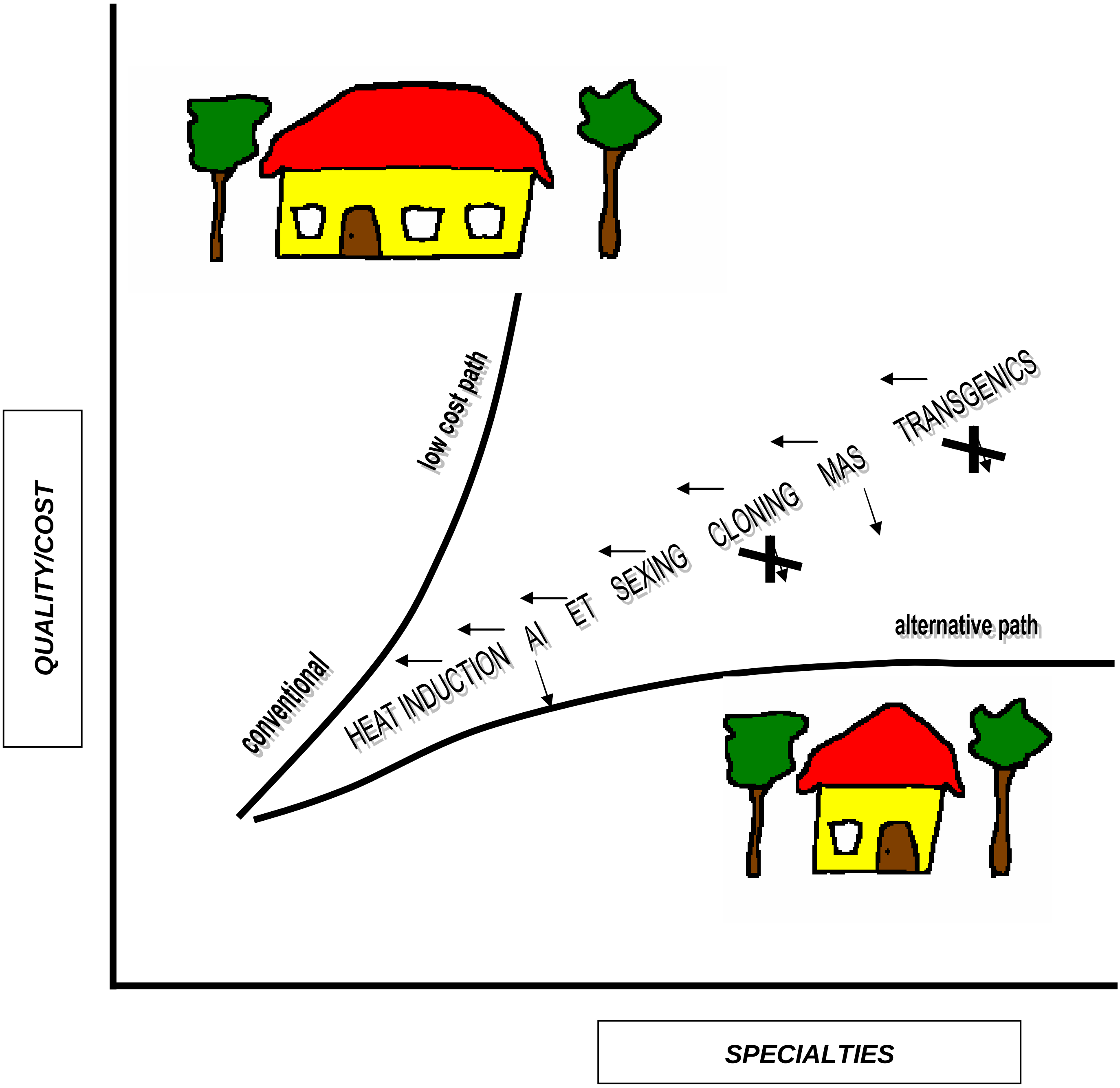

Figure 1. The overall picture of possibilities – moderate, alternative or just convenient for the consumer – gives an idea of the choices that can be made

Directly livestock production and thus animal breeding are influenced by the consumer purchases. This is the most powerful way of influencing the way food is produced. Any discussion to influence decisions in selection programmes and farming systems should address the consumer needs and the public desire, bearing in mind that

a) changes in breeding goals will not give results now but in five or ten years or more from now. In setting breeding goals, the consumer and societal wishes of a future that lays a decade or more ahead need to be predicted,

b) the actual economical system is moving towards market globalisation, and

c) not everything can be reached by breeding. Breeding is a tool that can be used alongside other management tools. Genetic improvement is a part of the production chain, dealing with the choice of the parents of the next generation, and with the production of this generation. The farming system and the technologies involved (the environment) play the other large role in animal production. Even for characters with a very high heritability of 40 %, 60 % of the eventual expression for this character would still be determined by factors in the environment.

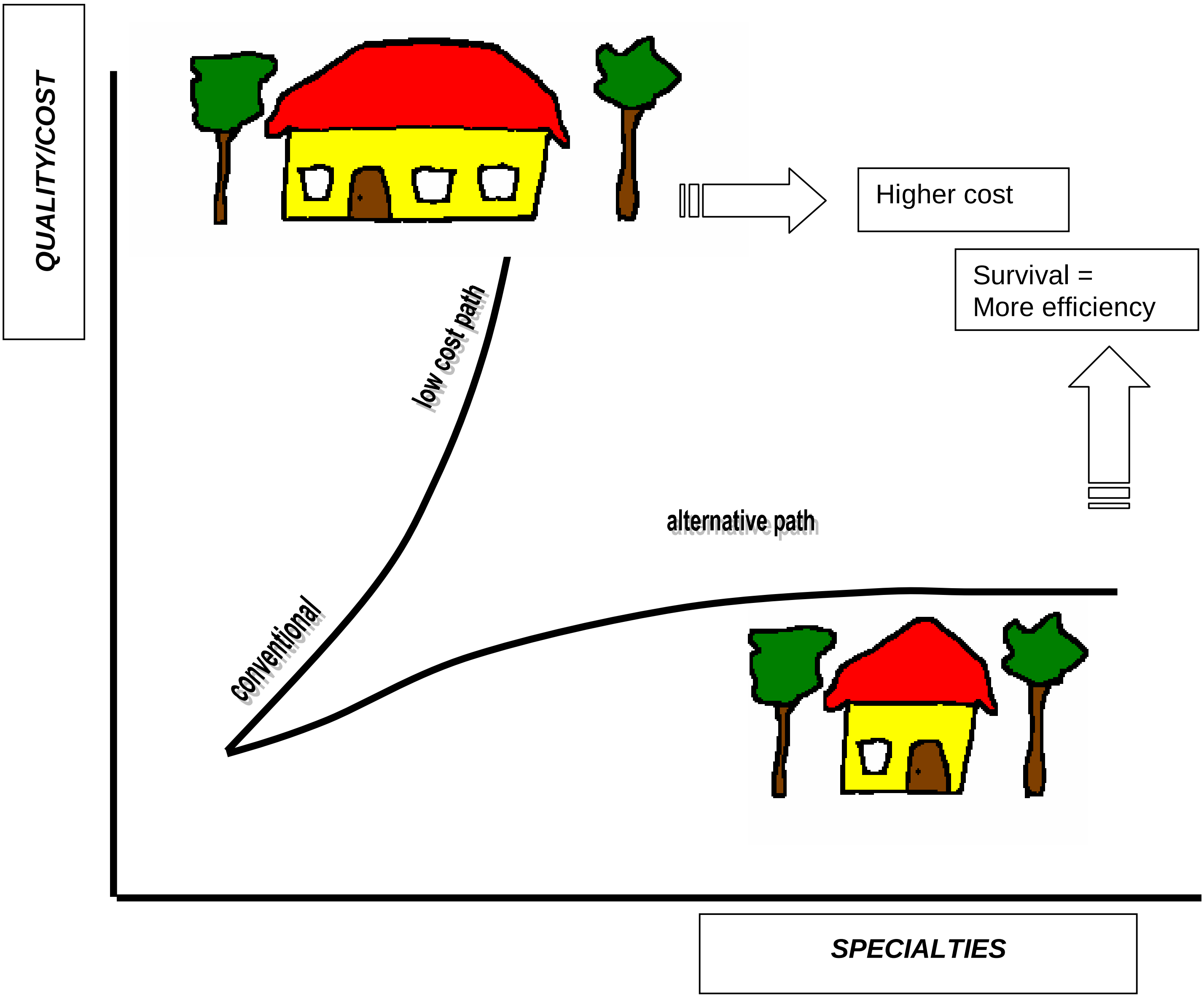

Figure 2. The ideas and experience in the alternative path can be used by the farmers in the low cost path and vice versa

The future reality could fit into the pre-described conventional, alternative or low-cost path, but it could also present a variety of the different production systems. There is no clear answer to what should be the future scenario. They could co-exist and the one could benefit from the other. The ideas and experience in the alternative path could be used by the farmers in the low cost path and vice versa (Figure 2). Also in the future, the wish to express cultural differences in Europe could lead to different farming systems. Part of the differences might be due to different levels of acceptance of technologies involved in the production system or different perceptions of quality and price. Furthermore, consumers may want to have a freedom of choice in their purchases.

In order to be able to adapt to the wishes of society, it will be important to know what society really wants. How much would one be willing to pay in terms of money, sustainability, or land that could not be used for leasure, nature or tourism if it should be used for more extensive production? What could be the value of food labelling and trademarks for production systems? How important is the right to have local and cultural differences in Europe? What would Europe be willing to pay in WHO negotiations in terms of trade barriers? Hopefully the scenarios can initiate a fruitful discussion on the future of farm animal breeding in which users and producers weigh the possibilities and price of the different breeding goals, using all or part of the available technologies, and representing different production systems.

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