THE ROLE OF BIOTECHNOLOGY IN IMPROVING ANIMAL AGRICULTURE AND THE QUANTITY AND QUALITY OF FOOD FOR CONSUMERS

R. G. CAMPBELL

Summary

Consumers have been the major beneficiaries of the tremendous improvements in the efficiency and cost of pig meat production and in agricultural science and production in general which have occurred over the last 10 years. The benefits have flowed to consumers firstly in the form of lower prices resulting from improved margins and increased output at the production level and secondly in the form of better quality food products. For example improvements in genetics and nutrition over the last 10-15 years have reduced the carcass fat content of pigs by as much as 40%. Future improvements in productivity and in the price and quality of agricultural products available to consumers however, will be more difficult to achieve. Indeed, it is unlikely that the more traditional techniques will enable the efficiency of agriculture and animal agriculture in particular to be improved rapidly enough over the next ten years to keep pace with the rapid decline in trade faced by most agricultural enterprises.

I. INTRODUCTION

The benefits offered consumers by the technical advances made in agriculture over the last 10-20 years are going to be difficult to sustain using traditional techniques such as genetic manipulation, nutrition, animal health and management. The slowdown is not particularly bad since it would tend to result in a decline in production and increase in the price achieved by the producer. However, consumers continue to demand cheaper better quality foods and the fact that agricultural production is now more global than national would mean that price advantages of this type would be short lived.

The mechanisms underlying the performance characteristics of most domestic animal species are well understood. Ensuring maximal profitability is largely a matter of understanding and implementing this knowledge at a practical level in the short term and of developing techniques and technologies to alleviate or remove the major constraints in the longer term.

In the present paper I have concentrated on animal agriculture and the pig industry in particular to demonstrate just how much we know about the factors influencing protein deposition capacity and how biotechnology can play a role in improving both the cost and quality of food in the future. Longer term improvements in the efficiency of livestock production will be dependent on identifying and removing or at least alleviating current constraints to protein deposition capacity. In the later parts of the present paper I have concentrated on two biotechnologies which have the potential to make pig meat production the most efficient animal production system in the world and to provide consumers with cheaper meat products with whatever fat and lean content might be desired.

II. THE BASIC CONCEPTS AND CONSTRAINTS

Differences in growth performance and body composition have been reported between

Bunge Meat Industries Limited, PO Box 78, Corowa, New South Wales 2646

animals of different sex and strain by numerous authors (Siebrits and Kemm 1982; Webster et al. 1977). However, until more recently the mechanisms underlying these differences remained unclear. The results of an experiment by Campbell and Taverner (1988) in which protein deposition was measured in two strains of intact male pigs over a range of energy intakes (Table 1) showed that the relationship between energy intake and protein deposition is, at the tissue level at least, the major factor determining the performance capabilities and energy partitioning of growing animals.

The form of the relationship is of the linear plateau form with the plateau representing an intrinsic limit to protein deposition. Increasing the slope of the line component of the relationship or the plateau value will result in faster, more efficient and leaner growth (Table 1). Both these components of the relationship are altered by genetic selection although the rate of change in either component will depend on the selection technique employed.

Table 1. Effects of energy intake between 45 and 90 kg liveweight on protein deposition and growth performance in faster (A) and slower (B) growing strains of entire male pigs (Campbell and Taverner 1988).

Energy intake (MJ De/d)	Strain	Protein deposition (g/d)	Daily gain (g)	Feed:gain	Carcass fat (%)
22.2	A	92	567	2.60	18.8
	B	81	470	3.12	24.4
25.1	A	105	622	2.66	19.4
	B	87	595	2.80	26.6
27.6	A	119	764	2.39	21.0
	B	105	680	2.69	29.0
30.6	A	135	826	2.40	23.6
	B	115	734	2.77	28.9
33.5	A	148	944	2.36	25.4
	B	128	820	2.70	30.3
36.8	A	166	1110	2.23	25.8
	B	129	870	2.85	32.2
Ad libitum[a]	A	189	1202	2.26	26.0
	B	125	915	3.05	36.6

[a] Ad libitum energy intake was 40.6 and 40.7 MJ DE/d for strain A and B pigs respectively.

Future improvements in the efficiency of animal agriculture will clearly depend on better understanding the cellular and hormonal controls of protein deposition and using this information to develop techniques for removing the upper limit to protein deposition and/or increasing the slope of the linear component of the relationship between energy intake and protein deposition.

III. CONTROL OF PROTEIN DEPOSITION

It is now established that protein and energy metabolism in growing pigs and most other livestock species is under the control of growth hormone or somatotropin (ST). For example in pigs the decline in the slope of the linear component of the relationship between energy intake and protein deposition with age is due to a decline in the synthesis and release of porcine somatotropin (PST) (Campbell et al. 1991).

Growth hormone controls and coordinates protein and lipid metabolism by acting directly on adipose tissue to inhibit lipogenesis and indirectly via insulin growth factor I (IGF-I) to stimulate protein deposition (Campbell et al. 1990). It is also known that the synthesis and or release of IGF-I by PST is dependent on amino acid intake and that the anabolic and anti-lipogenic effects of PST can be separated by using protein deficient diets (Campbell et al. 1991). All of this information provides numerous direct and indirect options for further improving the efficiency of pig production and quality of meat products.

IV. BIOTECHNOLOGY

There are many more biotechnologies available or being developed for animal agriculture in general and pig production in particular than the two discussed in detail here. These include steroid hormones, the beta agonists, auto immunization techniques and a variety of growth factors. However, with the possible exception of the beta-agonists which have been reviewed by Dunshea (1994) their effects on protein and lipid metabolism are relatively small and poorly understood. In contrast exogenous PST administration stands alone as a means of enhancing protein deposition capacity and potentially for revolutionizing pig production.

(a) Exogenous PST administration

The effects of exogenous PST administration on the protein deposition and growth performance of entire male pigs between 60 and 90 kg is shown in Table 2.

Table 2. Effects of exogenous porcine somatotropin (PST) administration and dietary lysine content between 60 and 90 kg on the growth performance and carcass P2 fat thickness of entire male pigs (Campbell et al 1991).

PST (mg/kg/d)	Lysine (%)	Protein Deposition (g/d)	Daily Gain (g/d)	Feed:gain	Ps (mm)
0	0.45	67	628	3.71	20.5
	0.66	107	803	2.86	19.8
	0.88	118	862	2.65	18.6
	1.09	115	823	2.78	20.2
	1.31	119	887	2.63	17.2
	1.53	117	860	2.71	18.4
0.09	0.45	74	588	3.87	17.0
	0.66	104	760	3.02	15.0
	0.88	146	961	2.35	12.4
	1.09	175	1108	2.07	14.2
	1.31	216	1204	1.80	14.0
	1.53	213	1338	1.69	13.1

Exogenous administration of PST between 60 and 100 kg can increase and reduce protein and lipid deposition rates by 30 and 45% respectively resulting in improvements in growth rate and feed efficiency and reductions in the fat:protein ratio of the tissue growth and carcass and body fat content. The latter effects are further demonstrated in Table 3 which gives the carcass composition for pigs administered PST from 30 to 60 kg. It is evident from these data and that given in Table 2 that the major impacts of technologies such as the use of recombinant PST are on the efficiency and cost of growth and on the fat content of the product produced. PST technology allows the intrinsic constraints to future improvement in the efficiency of meat production to be removed and the quality of the final product to be improved. The responses are dose dependent and independent of genotype. Providing the dose is kept within the range three to 10 mg/pig/d from 60 to 110 kg the technique has no adverse effects on animal health. The technology is simply a means of overcoming a decline in endogenous PST release which occurs with age in growing pigs and as such is completely safe for consumers of the final product. The technology has the further advantage that the improvement in carcass lean content is not achieved at the expense of meat quality whether assessed on the basis of colour, tenderness or drip loss.

Exogenous PST administration is registered for commercial use in Australia and it certainly has the potential to revolutionize the industry and provide consumers with some of the leanest meat available at lower cost. The major constraint to the adoption of the technology is likely to be the fact that the material currently has to be administered daily or bi-daily using a rapid injection device. Fear of adverse consumer reaction may also be a factor influencing the use of PST. This will be eventually be overcome by new technology. This concept is probably minor and can be overcome by support for the technology from the human health and nutrition communities.

Table 3. Effects of exogenous porcine somatotropin (PST) administration and dietary protein content between 30 and 60 kg live weight on the carcass composition of pigs at 60 kg liveweight (Campbell et al. 1990).

PST (mg/kg/d)	Dietary protein (%)	Water (%)	Protein (%)	Fat (%)	Ash (%)
0	8.3	51.1	14.7	31.1	3.02
	11.4	55.8	16.3	24.7	2.82
	14.5	57.0	16.6	24.2	2.62
	17.6	59.1	17.5	20.8	2.68
	20.7	57.8	16.8	22.1	2.72
	23.8	58.8	17.2	21.2	2.77
0.09	8.3	53.8	15.6	27.6	2.92
	11.4	58.4	16.8	21.9	2.80
	14.5	61.3	17.6	18.0	3.02
	17.6	63.1	18.2	15.6	3.00
	20.7	64.1	18.4	14.7	2.72
	23.8	65.1	18.8	13.5	2.54
SEM		0.99	0.31	1.21	0.15
Significance (P value)					
PST (P)		0.01	0.01	0.01	NS
Dietary protein (DP)		0.01	0.01	0.01	NS
P x DP		NS	NS	NS	NS

(b) Transgenesis

The potential problems with delivering PST commercially may be overcome by the development of pigs transgenic for the gene. An Australian biotechnology company, namely, Bresatec has continued to invest in the development of pigs transgenic for PST. Their program leads the world and has resulted in the development of large numbers of founder stock in which the expression of the gene construct is controllable. This is shown in Table 4 which gives the plasma IGF-I levels of a number of founder boars transgenic for the PST gene. Expression of the gene is controlled by dietary zinc and it is well established that IGF-I is the mediator of the anabolic actions of PST. These results are extremely promising firstly because all the animals produced to date are healthy and fertile and secondly because gene expression is controllable.

The value or otherwise of the technology for increasing the quantity and quality of pig meat and pig meat products available to the consumer will have to await full evaluation of the F1 progeny. Nevertheless, the technology represents the next major step forward in animal genetics and certainly has the potential to provide the industry with major advantages against competing products and to provide Australia with a similar advantage over its global competitors.

Table 4. Effects of dietary Zn on the plasma IGF-I levels of boars transgenic for the PST gene.

Boar no.	Plasma IGF-I (ng/ml)		
	Low zinc (100 ppm)	High zinc (1000 ppm)	Low zinc (100 ppm)
Control	184	201	194
TG50405	190	220	184
TG50406	196	326	208
TG50408	192	338	226
TG50410	222	750	288
TG50411	184	201	196

The potential of transgenic technology for providing consumers with a better quality product is further illustrated in Table 5 which presents the carcass composition results of control pigs and pigs transgenic for bovine growth hormone between 14 and 92 kg live weight.

Table 5. Comparison of total carcass lipid and cholesterol content of transgenic and control pigs (Solomon et al 1994).

	Total Lipid (g/100 g)		Cholesterol (mg/100 g)	
	Control	Transgenic	Control	Transgenic
Liveweight (kg)				
14	10.04	6.19	100.9	106.5
28	12.32	7.62	95.0	100.0
48	16.58	8.16	85.9	86.3
68	26.78	5.97	74.2	74.6
92	29.07	4.49	77.8	77.1

V. CONCLUSIONS

There is no doubt that biotechnology has the potential to improve the quantity, price and quality of foods available to consumers. To date the biggest impact on biotechnology on agriculture has been in increasing our understanding of the mechanisms controlling growth and development, which in turn has led to the development of techniques for improving the efficiency of production and the quality of the final products. The two technologies discussed in the present paper are associated with manipulation of metabolism and in particular protein and lipid metabolism at the DNA, cellular, hormonal and tissue levels. However, knowledge of the basic mechanisms controlling growth and development should and will enable genetic selection to become more precise and biologically based. The latter may enable the rates of genetic progress in the traits required to make animal agriculture more efficient to be increased two to three fold what they are at present. Similarly we know that the synthesis and/or the release of IGF-I is inhibited by low amino acid intake. It is possible that particular amino acids or peptides are involved in this process and that enhancement of protein accretion may be possible via the diet. Manipulation of the animal will always result in the greatest improvements in the cost of production and product quality since improvement in protein deposition improves the efficiency with which energy is used for growth and reduces the fat:protein ratio of growth. Nevertheless, biotechnological advances are not limited to animals and improvement in the yield, nutritional value or manufacturing properties of cereals and pastures will also increase the competitiveness of animal agriculture resulting in cheaper but not necessarily better quality meat products for consumers.

A number of biotechnologies are currently available and being used to improve agriculture and provide more and better food for consumers. For example bovine somatotropin (BST) is approved and being used in the USA for improving the efficiency of milk production. Two transgenic tomatoes have been released for commercial production and sale in the USA, exogenous PST administration is approved and available to improve the efficiency of pig meat production in Australia and the first meat produced from pigs transgenic for PST should be available by the end of 1995. These technologies are safe and represent the future direction of agriculture because without them most agricultural enterprises considered successful today will become unviable and consumer expectations with respect to the quality and price of food will be difficult to achieve.

REFERENCES

CAMPBELL, R.G. and TAVERNER, M.R. (1988). J. Anim. Sci. 66: 676.
CAMPBELL, R.G., JOHNSON, R.J., KING R.H., TAVERNER, M.R. and MEISINGER, D.J. (1990). J. Anim. Sci. 68: 3217.
CAMPBELL, R.G., JOHNSON, R.J., TAVERNER, M.R. and KING R.H (1991). J. Anim. Sci. 69: 1522.
DUNSHEA, F.R. (1994). Proc. Nutr. Soc. Aust. 18: 102.
SOLOMON, M.B., PURSEL, V.G., PAROCZAY, E.W. and BOLT, D.J. (1994). J. Anim. Sci. 72: 1242.
SIEBRITS, F.K. and KEMM, E.H. (1982). In 'Energy Metabolism of Farm Animals'. p 237. European Association for Animal Production Publication 29. (Vitzan: Switzerland).
WEBSTER, A.J.F., SMITH, J.S. and MOLLISON, G.S. (1977). Anim. Prod. 24: 237.