The bovine genome and human nutrition

Human nutrition

Living processes require energy and so the most basic function of food is to supply us with energy – typically 8 to 12 MJ (million *joules*) per day (equivalent to 2000 to 3000 *kilocalories* per day), depending on a person's general activity level.

Our energy requirement is met mainly by *carbohydrates*. However, a human being would not survive on a diet of sugar alone. Our diet should also contain water, *protein*, *fat*, and small amounts of certain *minerals* and *vitamins*. It is also desirable to include a certain amount of *roughage* in the diet.

1 kcal = 4184 J = 4.184 kJ;
1 kilocalorie is often written as 1 *Calorie* (with a capital 'C')

Average human daily requirements

A balanced daily diet should provide about 10 MJ of energy, about 70 g of protein and about 20 g of fat, as well as essential *micronutrients* (i.e. minerals and vitamins). Bread, potatoes and rice contain 30% to 50% starch (a carbohydrate) and could supply most of the energy requirement. The nutritional components of some common foods are shown in the table.

Cattle breeds in Ireland

In Ireland there are about 5 million beef cattle and 1.4 million dairy cows. The annual beef output is approximately 500,000 tonnes, 90% of which is exported – mainly to the UK. The annual milk output is about 6 billion litres, 85% of which is exported as milk or dairy products.

	Carbohydrate	Protein	Fat	Energy	
	(g)	(g)	(g)	(kJ)	(kCal)
Milk (whole)	5	3	3	255	60
Beef (lean, cooked)	**0**	**30**	**10**	**910**	**220**
Egg (cooked)	1.6	10	11	625	150
Potatoes (cooked)	20	1.7	0.1	360	86
Bread	49	9	3	1100	265

Some cattle breeds are good for milk production while others are good for beef. In order to produce milk, dairy cows must calve each year. Some of the calves are needed to replace stock, but most are reared for beef production. In Ireland, pure dairy farming is rare and most cattle are 'dual purpose', i.e. they are used for beef and milk production. About 92% of dairy cattle (47% of all cattle) in Ireland are Friesian or Friesian *crosses*, such as Holstein-Friesian. About 50% of the dairy calves, and 20% of beef calves, are sired through *artificial insemination*. About 20% of all calves (and 50% of beef calves) are sired by *Charolais* or *Limousin* bulls.

Beef breeds	Dairy breeds
Charolais	Friesian
Hereford	Jersey
Angus	Kerry
Limousin	Holstein
Simmental	

Genomics

Cattle have had a long relationship with people, as a means of converting inedible grass into human food. They have also been used as working animals and as a source of useful materials such as leather.

Advances in technology have enabled scientists to determine the *genome* of *microorganisms*, plants and animals. The genome is the complete set of genes of an organism, i.e. the genetic code for its hereditable characteristics. A gene is a section of DNA that codes for a protein or other functional unit, such as an *RNA* chain.

Growing *databases* of genetic information, speed of analysis and increased computer capability have led to insights unimaginable even a few years ago. Through the international collaboration of many scientists, the genome of cattle was finally determined.

Genomic analysis involves mapping an organism's *DNA*. Sequencing of *mRNA* produced at different stages in an organism's life cycle indicates when specific genes are active. *Proteomic analysis* for the proteins present in the cell at these times provides further information; this analysis is important because the mere presence of a gene does not necessarily mean a particular protein is produced.

If a *gene sequence* seems to code for an unknown protein, the protein structure can be *hypothesised* using computer software and its function guessed at. Scientists have identified millions of *SNPs* (*single nucleotide polymorphisms*), variations of a single *nucleotide* at different loci on *chromosomes*. Comparisons of SNPs in different animal breeds can give insight into *phenotypic variations*.

Milk production

Genes associated with milk production are of major interest. Milk is the only food specifically designed to nourish young mammals. Producing it takes energy and resources from the mother and so it should not contain superfluous materials.

The bovine genome and human nutrition

Milk has essential nutrients, protective molecules and immune system promoters, as well as *oligosaccharides* that promote the growth of beneficial *gut microflora*.

Desirable characteristics

In the short term, scientists are hoping to identify genes and groups of genes associated with characteristics in cattle that are relevant to food production. These include meat quality, milk quantity and composition, growth to feed ratio, appetite, animal temperament, reproductive capability, disease resistance and meat tenderness. Conversely, a poor rating on any of these characteristics would be undesirable.

Genetic profiling of calves

Calves can be tested at birth to determine whether they have genes that would make them desirable for breeding. These animals can be *inbred* to obtain pure-breeding stock. This process would be a significant improvement on traditional breeding programmes where animals are produced with good phenotypic qualities, but farmers would have to wait up to five years for confirmation that the animals could actually transmit these characteristics to their offspring.

Genetic testing can also detect undesirable genes in healthy *heterozygous* animals, enabling them to be excluded from breeding programmes and reducing the frequency of that gene in the population. For example, bulls carrying a recessive *allele* of the CD18 gene (lethal if homozygous) have been identified and removed from the breeding stock.

Conclusion

Identifying genes or groups of genes that are associated with desirable and undesirable characteristics in cattle is a valuable aid to breeding and food production in general. Comparison of the genetic make-up of individual animals, different breeds or similar breeds raised in different environments provides further insight. Much more research is needed before an understanding of the genome and gene action reaches a point where its true potential can be realised. Developments in knowledge and techniques have been rapid in recent years and so the prospects are encouraging.

Overall, genomics is still in its infancy.

Teagasc is Ireland's agricultural and food development authority supporting science based innovation in the agri-food sector and the wider bioeconomy to underpin profitability, competitiveness and sustainability. Through research, (food and agriculture) and knowledge transfer (advisory and education) Teagasc delivers six programmes:

- Animal and Grassland Research and Innovation Programme
- Crops, Environment and Land Use Programme
- Rural Economy and Development Programme
- Food Programme
- Education Programme
- Advisory Programme

Teagasc employs over 120 scientists and 120 technicians in research, 30 specialist staff, and over 320 advisers/teachers in education and advisory roles. In total, over 1,200 staff are employed at over fifty locations throughout the country. The research carried out by Teagasc is essential to the development of competitive and sustainable agricultural and food industries.

Find out more about the work of Teagasc at http://www.teagasc.ie/

ICBF (Irish Cattle Breeding Federation) exists to benefit our farmers, our agri-food industry, and our communities. It does this through the development and application of science and technology, ensuring that our farmers and our industry make the most profitable and sustainable decision. In 2012/2013, the major contributions ICBF made towards its mission included:

- The establishment of a new Gene Ireland Beef programme to help ensure that Ireland is breeding a profitable suckler cow
- The beginning of genomic testing of pedigree male calves which will set Ireland on its way towards Genomic Selection for the Suckler Industry.
- Further enhancements to the €uro-Star beef genetic evaluations by utilising the wealth of data becoming available through the Department of Agriculture data collection schemes.
- Growth in the HerdPlus® service to beef and dairy herds by 9%.
- Continued increases in the EBI's of bulls available through AI to Irish Dairy farmers.
- Continued publication of reports on key performance indicators of the dairy herd in collaboration with milk processors.

Find out more about the work of ICBF at http://www.icbf.com/

Syllabus References

Junior Certificate Science

Genetics. 1B5, OB35 – 37

Leaving Certificate Biology

2.3 Cell continuity

2.5 Genetics

Leaving Certificate Agricultural Science

Principles of genetics

Structure and function of the animal body

The cow

Science and Technology in Action is widely used for project work in **Transition Year**.

Learning Outcomes

On completion of this lesson, students should be able to:

- Explain the key terms used in the lesson.
- Outline how the development of these sciences has positive implications for bovine meat and milk production.
- Describe how research in bovine genetics can be used to improve meat and milk production.
- Outline where genetic techniques are being used today.
- Describe some of the challenges in this developing area of research.

General Learning Points

The following points can be used to enhance the lesson content and to inform discussion.

- Balanced diets are more easily devised if animal produce is included. Vitamin B12 can only be obtained from animal sources. Protein obtained from animals more closely resembles human protein than that obtained from plants so qualitatively it may be somewhat superior.
- SNPs (single nucleotide polymorphisms) are variations of a single nucleotide at a locus on a chromosome. A haplotype is a combination of SNP variants. HapMap projects in humans, cattle and other organisms create maps of different haplotypes to identify common blocks of genetic variation inherited together in different populations. The identification of haplotypes associated with desirable characteristics has relevance to bovine agriculture. Animals carrying undesirable genes can be identified and prevented from breeding.
- Genomics works better for comparisons within, rather than across, cattle breeds. The heritability of traits has so far proved more predictable in dairy than in beef cattle.
- Genetic techniques have made lab-grown food a possibility.

Student Activities

1. List the different breeds of cattle used in Ireland. Outline the characteristics that make them useful. Why do some charitable organisations provide European cattle breeds to poorer countries rather than develop existing native breeds?
2. Cloned cattle may be generated as follows. The nucleus is removed from the fertilised egg of a cow and replaced with a nucleus obtained from the tissue of another breed. This modified egg is re-introduced into the uterus of the cow that provided the egg. She then delivers and raises the calf. What characteristics do you think each animal might have? What are the advantages and disadvantages of the entire process?
3. Southern blotting. Mass spectrometry. Reverse transcriptase. PCR (the polymerase chain reaction). These are chemicals or techniques employed in genetics research. Make out separate posters to explain the use of each, and any other methods you are aware of.
4. RNA carries codes for amino acids in the form of base triplets. The bases are adenine(A), uracil(U), guanine(G) and cytosine(C). Lysine is coded for by AAA or AAG. Alanine is coded for by GCU, GCC, GCA or GCG. Stop codons (indicating the end of a protein) are UAA, UAG or UGA. Make a list of amino acids and their codons. Examine the effects on codons of mutations involving a single base change.
5. Construct a poster showing the evolutionary tree for cattle.
6. List the characteristics that would be necessary for survival in wild cattle but might not be beneficial in farm animals.

True/False Questions

a) Genomic analysis can help improve the traceability of meat. T F

b) Cattle and humans are the only organisms whose genome has been determined. T F

c) The genetic diversity of cattle has increased since they were first domesticated. T F

d) The cow genome has approximately 22,000 genes. T F

e) Determination of all protein functions in a cell is a slower process than establishing its genome. T F

f) Success rates in producing transgenic cattle are currently fairly low. T F

g) Knowing genomes and proteomes can help scientists identify proteins associated with disease states. T F

h) Metagenomics involves the analysis of DNA collected in the environment. T F

i) The presence of a gene always implies the presence of an associated protein. T F

j) Characteristics considered desirable in an animal now may not always be regarded as desirable in the future. T F

Check your answers to these questions on www.sta.ie.

Examination Questions

Leaving Certificate Biology 2013 (HL) Q. 6

(i) In DNA, nitrogenous bases occur in complementary pairs. Explain the term complementary as used here.

(ii) In each case, name the complementary base in RNA for: adenine and cytosine

(iii) Name a carbohydrate that is a component of nucleotides.

(iv) Name a component of a nucleotide that is neither a carbohydrate nor a nitrogenous base.

(v) What does the 'm' stand for in mRNA? (ii) Give one difference between RNA and DNA, other than the nitrogenous bases.

(vi) Give the role of the enzyme RNA polymerase.

Leaving Certificate Biology 2012 (HL) Q. 6

(a) In genetics, what is meant by the term variation?

(b) Variation can result from mutation. Name one other cause of variation.

(c) Name two types of mutation.

(d) Name two agents responsible for increased rates of mutation.

(e) Briefly explain the significance of mutation in relation to natural selection.

Leaving Certificate Agricultural Science 2011 (HL), Q. 7

(a) Explain each of the terms: interphase, haploid and inbreeding.

(b) A maize plant, heterozygous for the recessive alleles hairless tassel (h) and short anther (l), is self-fertilised and the seeds are collected. The genes for tassel type and anther length are not linked. Use a cross to illustrate what proportion of the offspring you would expect to show (i) hairy tassel, (ii) short anther (iii) hairy tassel and short anther.

(c) Roan coat colour in Shorthorn cattle occurs as a result of incomplete dominance. Use a cross to show how roan coat colour arises from homozygous parents.

Leaving Certificate Agricultural Science 2010 (HL), Q. 3 (Option 1)

The calving records on a dairy farm in one year show: 30% purebred Friesian calves born, 55% Continental X Friesian and 15% Aberdeen Angus X Friesian.

The farmer relies on A.I. and has no stock bull. He breeds his own replacements.

(i) Why was the Friesian breed used and on which of his cows?

(ii) Why are continental sires used for most inseminations?

(iii) Why are Aberdeen Angus bulls used?

Did You Know?

- Cattle and humans share 80% of their genetic make-up. They are more closely related to us than are mice or rats, making them prospective experimental animals in the future.
- Epigenetics is the study of changes in gene expression or cellular phenotypes caused by mechanisms other than changes in the underlying DNA sequence. Mechanisms involve DNA methylation and histone modification. There is evidence in some cases that epigenetic changes are inheritable. Human twins raised separately have shown epigenetic variation. Diet and environment drive epigenetic processes.
- "Junk DNA" was so called because scientists thought it served no purpose. This view is changing as knowledge grows. Some of it appears to be involved in regulatory processes. "Silent mutations", nucleotide changes which have no effect on the protein produced by a gene, are now being associated with health effects. DNA sections previously classed simply as "non-coding" seem to have an influence on protein synthesis.

Biographical Notes

Robert Bakewell (1725–1795)

Robert Bakewell took control of his father's farm in Leicestershire in 1760, having travelled in Europe to learn farming methods. He pioneered grassland irrigation and experimented in manure application. Before his time, animals in a herd or flock were allowed to mate randomly. He segregated the sexes, deliberately breeding animals in an effort to combine useful characteristics. He developed the New Leicester breed of sheep and Dishley Longhorn cattle. These cattle ate less and put on more weight. His breeds were replaced but his methods survived and became the basis of modern selective breeding of farm animal. Remember that Bakewell lived about 100 years before Mendel. *(The painting is in Leicester Museum, England.)*

Revise The Terms

Can you recall the meaning of the following terms?
Revising terminology is a powerful aid to recall and retention.

artificial insemination, calorie, carbohydrates, Charolais, chromosomes, crosses, databases, DNA, fat, Friesian, gene sequence, genome, gut microflora, heterozygous, hypothesised, inbred, joules, kilocalories, Limousin, micronutrients, microorganisms, minerals, mRNA, nucleotide, oligosaccharides, phenotypic variations, protein, proteomic analysis, RNA, single nucleotide polymorphisms, SNPs, vitamins.

Check the Glossary of terms for this lesson on www.sta.ie