Future (of) GM feed ingredients for livestock

Drivers for GM products in feeds

1. Agronomic traits providing increased yield or efficiency
   - Pest resistance
   - Stress resistance
   - Herbicide tolerance
2. Non-food use of crops
   - Pressure on existing feed use
   - Novel co-products

Drivers for GM products in feeds

3. **Nutritional enhancement – improved livestock performance**
   - **Aquaculture**
   - **Market dominance of soybean**
   - **Amino acid profile**
4. **Feed additives**
   - **Direct expression in crops**
   - **Efficiency of production**


Commodity crops

Agronomic traits

New crops – old traits

e.g.* *Herbicide-tolerant wheat, insect resistant legumes

Old crops – new traits

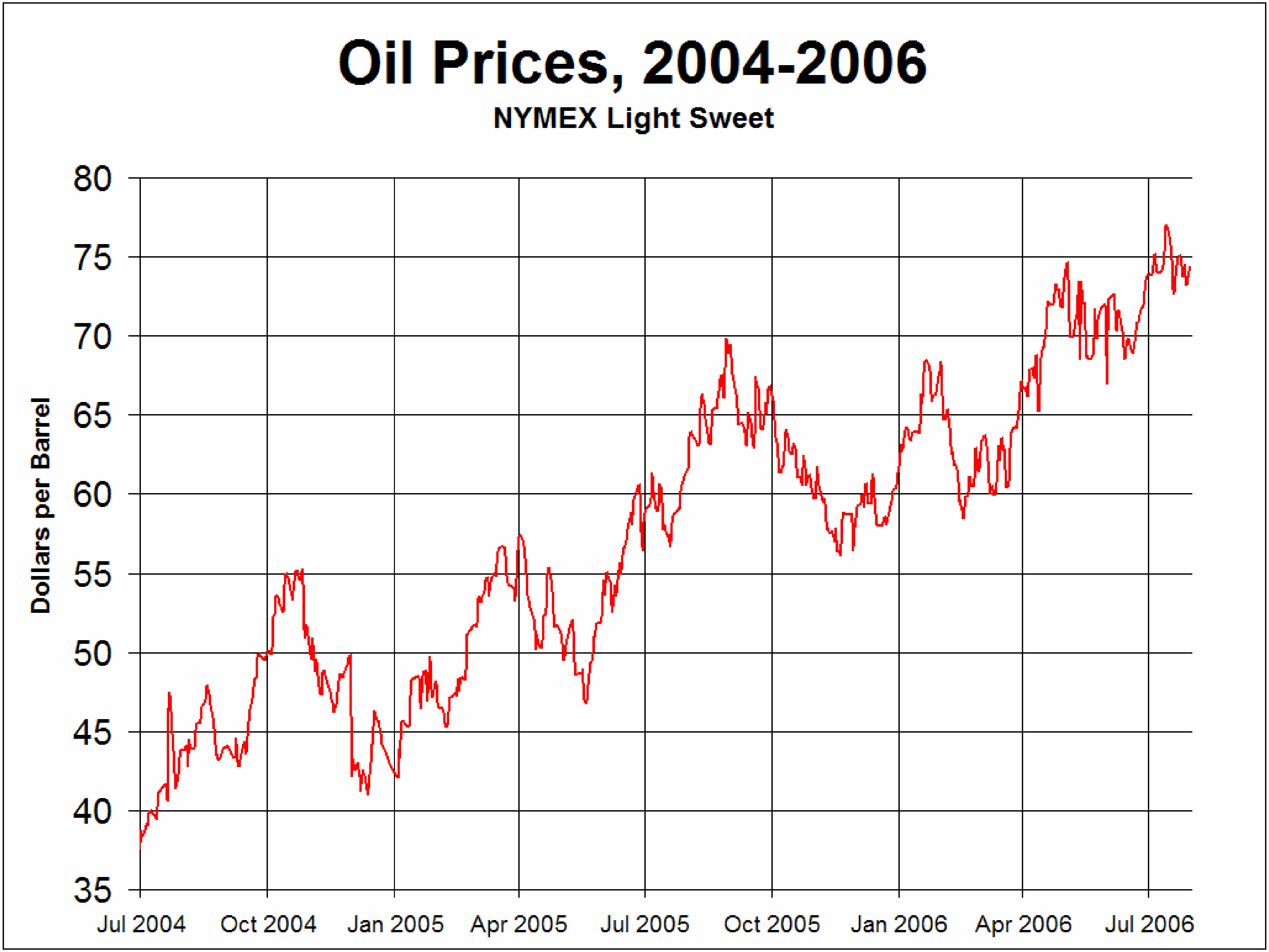
Increased stress tolerance

e.g.* *Nematode resistance in upland rice, flood tolerance in paddy rice

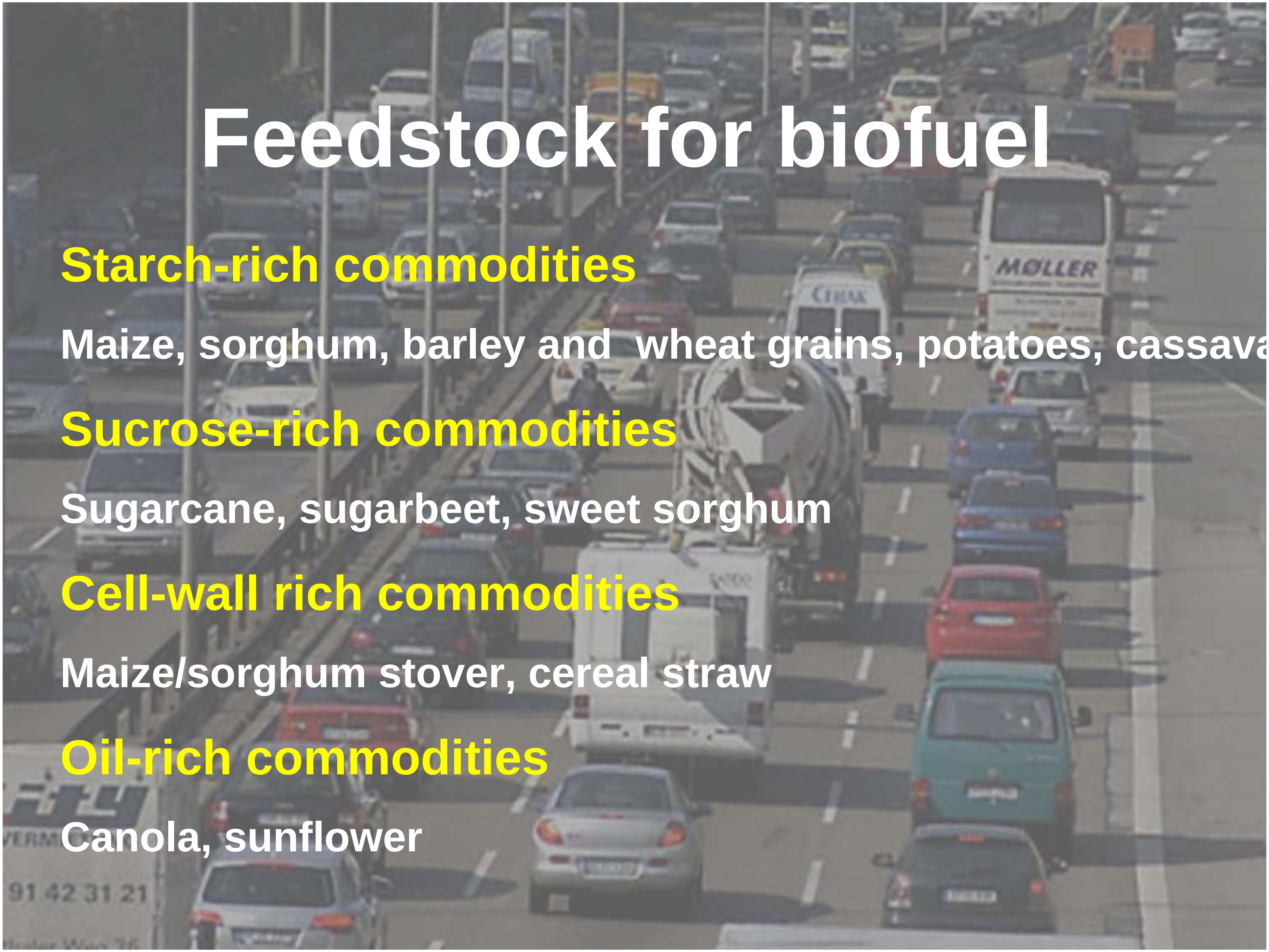
Agronomic traits and feeds

- Passive uptake of GM feed materials
- Active sourcing of non-GM materials in sufficient bulk for feed use is costly and increasingly difficult to sustain
- Absence of real consumer concerns about use of GM feed materials
- Pressure of non-feed demands likely to distort traditional patterns of use.

Non-food use of crops



Oil Prices, 2004-2006
NYMEX Light Sweet
Dollars per Barrel
80
75
70
65
60
55
50
45
40
35
Jul 2004
Oct 2004
Jan 2005
Apr 2005
Jul 2005
Oct 2005
Jan 2006
Apr 2006
Jul 2006



Feedstock for biofuel

Starch-rich commodities

Maize, sorghum, barley and wheat grains, potatoes, cassava

Sucrose-rich commodities

Sugarcane, sugarbeet, sweet sorghum

Cell-wall rich commodities

Maize/sorghum stover, cereal straw

Oil-rich commodities

Canola, sunflower


Market for oil seeds

- EU oilseeds market is largely influenced by the demand for biodiesel (80% from rapeseed oil)
- Demand for rapeseed now exceeds production.
- In N. Europe - crushers are turning from soybeans to multi-seed or rapeseed crushing
- Sunflower seed oil cheaper than rapeseed oil because of biodiesel
- Demand for sunflower oil is increasing and imports to the EU are growing


Nutritional enhancement

Traits available for manipulation in feed crops

- Gross composition (protein, lipid, CHO)
- Amino-acid balance
- Digestibility
- Micro-nutrients
- Storage and processing properties
- Reduced anti-nutritive factors
- Pre- and pro-biotic properties
- Added bioactive compounds
- Vaccines via feed crops

Improving plant nutritional value

- GE has notable advantages over conventional breeding.
  - size of the available gene pool
  - types of mutation possible
  - control of spatial and/or temporal expression of genes of interest
- Tissues consumed as feed are often not the tissues controlling growth and production

Example of lysine 1

- Lysine synthesis regulated by feedback inhibition of dihydrodipicolinate synthase
- Insensitive mutants of DHPS results in overproduction of lysine in all tissues
- High lysine in vegetative tissues causes abnormal growth, flowering and reduces seed yield
- Use of seed specific promoters eliminates undesirable effects

Example of lysine 2

- Accumulation of lysine negatively affected by its degradation to glutamate and acetyl CoA
- Seed-specific expression of DHPS mutant plus knockout of lysine catabolism accelerates lysine accumulation in seeds
- Knockout must be temporally regulated to occur during seed development, not germination

Example of lysine 3

Traditional maize breeding

- Yielded only the recessive *Opaque 2* and *Floury* mutants, lysine-rich but with poor seed quality and yield.

RNA interference technology

- Generated a dominant high lysine maize line by suppressing expression of a lysine poor zien protein without detrimental effects on seed quality

Example of methionine 1

- Young pigs and poultry have higher dietary requirement for sulfur amino acids than provided by grain-soybean meal rations.

- The poultry and swine industries spend an estimated $100 million annually augmenting feeds with synthetic methionine to promote optimal growth and development of animals consuming grain–soybean meal rations.

Example of methionine 2

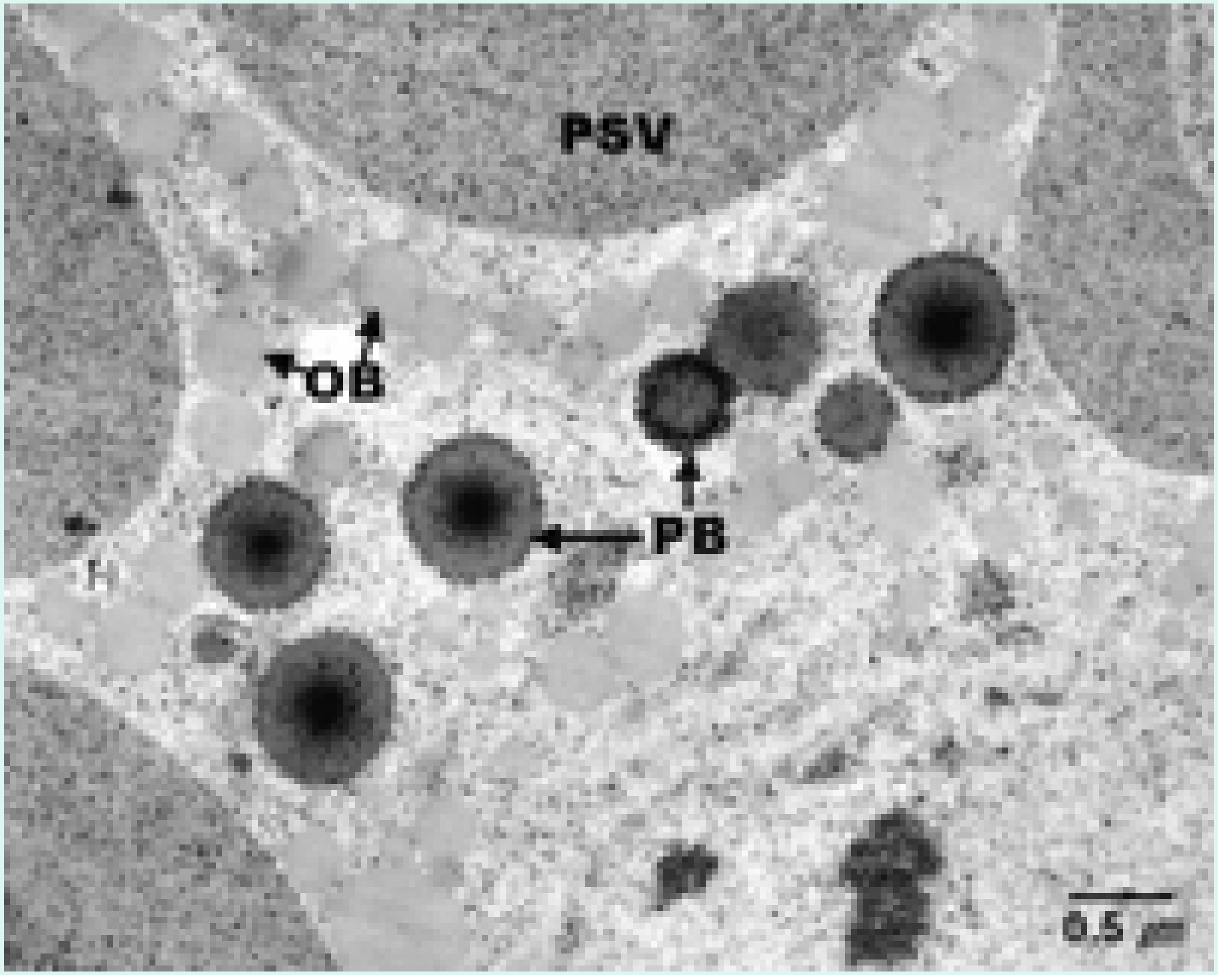
Traditional breeding

- Substantial increases in protein levels have been achieved by traditional breeding
- Lack of variability in methionine content among soybean cultivars has limited the use of conventional methods to increase the sulfur amino acid content.
- In general, the amount of sulfur amino acids has remained constant regardless of the amount of seed protein

Example of methionine 3

Genetic engineering

- Expression of heterologous seed proteins rich in sulfur amino acids
  - Brazil nut 2S albumin (18% methionine)
  - Sunflower 2S albumin (23% methionine and cysteine)
  - Maize delta zeins, (23% methionine)

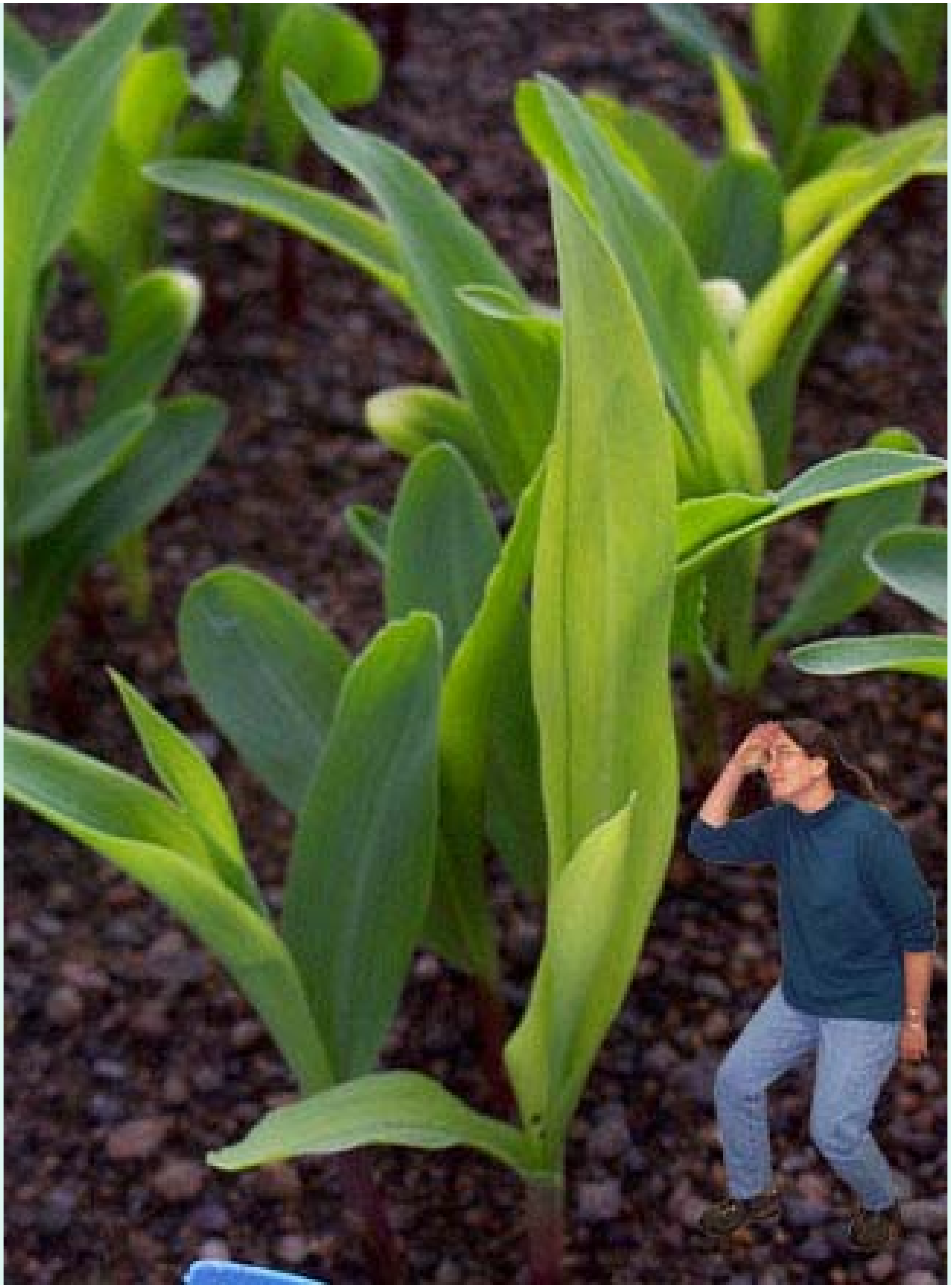


Endoplasmic reticulum-derived protein bodies (PB) in transgenic soybean.

From Krishnan (2005) Crop Sci. 45:454-461

Example of methionine 4

- Modification of abundant endogenous proteins
  - Insertion of methionine-rich sequence
- Elevating levels of endogenous sulfur-rich proteins
  - Albumin fraction (protease inhibitors)
- Expression of synthetic gene with well-balanced amino acid composition

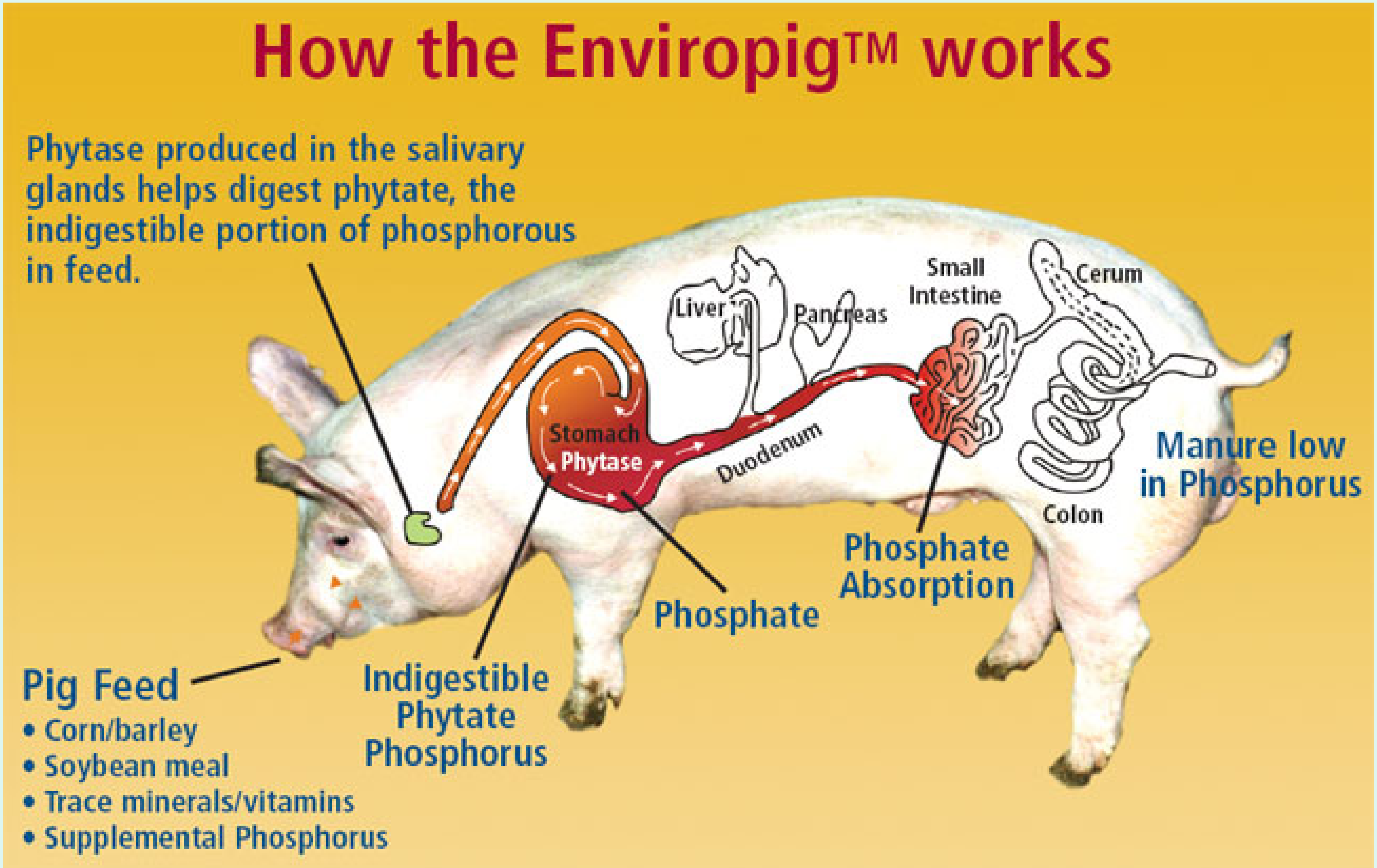


Feed additives

Feed additives from GE sources

- Enzymes
- Vitamins
- Amino acids
- Colourants

Currently produced in micro-organisms, but substantial progress made in expressing in plants e.g. phytase



Golovan ***et al*****. 2001.** ***Nature Biotechnology*** **19, 741-745**.

Conclusions

- Expect an expanding range of GE plants
- Likely to results in a greater volume and range of GE products and co-products available as feed
- Passive uptake by industry will continue unless consumer attitudes radically change
- Nutritional enhancement is scientifically possible but requires active uptake by industry and segregation of crop
- Investment needed will only be made in a favourable societal climate