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Preface

Humans are faced with major environmental challenges as a result of climate change and a predicted shortage of fossil fuels for transport. The underlying causes of climate change are not fully understood, but it is accepted that greenhouse gas (GHG) emissions, especially methane, are a contributory factor over which we can exert some control. The shortage of fossil fuels can be mitigated by blending them with biofuels, either ethanol with petrol, or biodiesel with diesel, both of which also result in a reduction in carbon emissions and for which minimum inclusion rates have been agreed. However, biofuel production is currently from agricultural crops, usually starch-containing cereals for ethanol and oilseeds for biodiesel. To be successful this approach must be economically sustainable and must not generate conflict with the traditional use of agricultural land in producing food and feed for humans and livestock. Both criteria can only be met if the residues of biofuel production, referred to as co-products, are fully utilized.

One of the objectives of producing this publication was to collate, discuss and summarize state-of-the-art knowledge on current and future availability of co-products from the feedstocks most used for the production of biofuels, and use of the co-products as livestock feed. The original feedstocks tended to be major agricultural crops, cereals, especially maize and wheat, and sugar cane for ethanol production, and soybean meal and rapeseed meal for biodiesel. An underlying feature has been the spread worldwide of an industry originally based in North America and Europe.

With an increasing need for biofuels and expanding markets for co-products, another objective was to summarize information on alternative feedstocks, with an emphasis on cellulosic materials and non-conventional sources. Many of these are grown on sub-prime land and have minimum requirements for irrigation and other inputs. Detoxification of some seed meals and cakes is necessary before they can be considered as feeds. With other crops, such as oil palm, promoting use of the residues and co-products available both from the field and processing is required. The potential contribution from micro-algae presents a new concept in that their production is not land-based and processing can be achieved through the use of coastal waters. Other developments include broadening of the use of co-products from ruminant, especially cattle, and pigs, to poultry and fish (aquaculture), enhancement of the availability of existing co-products, and the introduction of new ones.

The third objective of this publication was to identify gaps in knowledge and define research topics to fill them. Subjects predominating include standardization of product quality, needed to aid ration formulation; testing of new products; development of detoxification procedures; research on micro-algae; and life cycle analysis linked to traditional nutritional appraisal.

This publication covers a wide array of co-products and is a timely contribution as people's aspirations are rising, evident from an increasing demand for livestock products and an ever greater reliance on transport, whether by air, road or sea, coupled with the challenge of maintaining agricultural production when faced with global warming. We hope that this publication will be useful to policy-makers, researchers, the feed industry, science managers and NGOs, and will contribute to making information-based decisions on issues related to food-feed-fuel competition and emerging challenges of global warming, in addition to making the efficient use of a wide range of co-products from the biofuel industry as livestock feed.



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Abbreviations used in the text

A:P	Acetate-to-propionate ratio
AA	Amino acid
AAFCO	American Association of Feed Control Officials
ABARE	Australian Bureau of Agricultural and Resource Economics
ACC	Australian Commercial Cross
ADF	Acid-detergent fibre
ADFI	Average daily feed intake
ADG	Average daily gain
ADICP	Acid-detergent-insoluble crude protein
ADIN	Acid-detergent insoluble N
ADL	Acid-detergent lignin
AFEX	Ammonia fibre expansion
AFIA	American Feed Industry Association
AI	Artificial insemination
ALA	Alpha-linolenic acid
Ala	Alanine
ALP	Alkaline phosphatase
AME	Apparent metabolizable energy
AMEn	Apparent metabolizable energy corrected for zero nitrogen deposition
AMTS	Agriculture Modeling and Training Systems
APHIS	Animal and Plant Health Inspection Service [USDA]
Arg	Arginine
Asp	Asparagine
AST	Aspartate transaminase
ATNSKC	Alkali-treated NSC
ATP	Adenosine tri-phosphate
ATTD	Apparent total tract digestibility
AUD	Australian dollars
BLR	Bagasse leaf residue
BN	Binder treated
BOD	Biological oxygen demand
BP	Beet pulp
BRSL	Bagasse residue and stripped leaves
BRSLB	Bagasse plus stripped leaves-based feed block
BUN	Blood urea nitrogen
BW	Bodyweight
C/N	Carbon:Nitrogen ratio
Ca	Calcium
Ca(OH)₂	Calcium hydroxide
CABI	Commonwealth Agricultural Bureaux International
CB-1A	Castor bean 1 allergen

CBM	Castor bean meal
CBS	Cystathionine β -synthase
CCDS	Maize [corn] condensed distillers solubles
CCK	Cholecystokinin
CDO	Cysteine dioxygenase
CDS	Condensed distillers solubles
CF	Crude fibre
CFB	Commercial feed block
CFR	Code of Federal Regulations
CGE	Computable General Equilibrium
CIAT	International Center for Tropical Agriculture
CLA	Conjugated linoleic acid
CLAYUCA	Latin American and Caribbean Consortium to Support Research and Development of Cassava
CO	Carbon monoxide
CO₂	Carbon dioxide
CP	Crude protein
CPO	Crude palm oil
CSE	Cystathionine γ -ligase
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSM	Cotton seed meal
Cu	Copper
Cys	Cysteine
DCGF	Dry maize [corn] gluten feed
DCP	Digestible crude protein
DCU	Decentralized crushing unit
DDG	Dried distillers grain
DDGS	Dried distillers grain with solubles
DE	Digestible energy
DG	Distillers grain
DGNC	De-oiled groundnut cake
DGS	Distillers grain with solubles
DHA	Docosahexaenoic acid
DIM	Days in milk
DIP	Degradable intake protein
DJKM	Detoxified jatropha kernel meal
DJPI	Detoxified jatropha protein isolates
DJSM	Detoxified jatropha seed meal
DKC	De-oiled karanj cake
DM	Dry matter
DMD	Dry matter digestibility
DMI	Dry matter intake
DNCS	De-oiled neem seed cake
DNSM	De-oiled neem seed meal
DRC	Dry-rolled corn
EAA	Essential amino acid

EC	European Commission
ED	Effective protein degradability
EE	Ether extract
EFB	Empty fruit bunches
EIA	United States Energy Information Administration
EJ	Exajoule [10^{18} joules]
EKC	Expeller-pressed karanj cake
Embrapa	Empresa Brasileira de Pesquisa Agropecuária
EMS	Ear-maize silage
EPA	United States Environmental Protection Agency
EPA	Eicosapentaenoic acid
ePURE	European Renewable Ethanol Association
ERD	Effective ruminal degradability
ERS	Economic Research Service
ESR	Erythrocyte sedimentation rate
ETOH	Ethanol
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute
FASOM	Forest and Agricultural Sector Optimization Model
FCE	Feed conversion efficiency
FCM	Fat-corrected milk
FCR	Feed conversion ratio
FDA	Food and Drug Administration [USA]
FEDNA	Federación Española para el Desarrollo de la Nutrición Animal
FELCRA	Federal Land Consolidated Authority
FELDA	Federal Land Development Authority
FOBI	Feed Opportunities from the Biofuels Industries
FQD	Fuel Quality Directive [of the EU]
G:F	Grain-to-feed ratio [feed efficiency]
GCAU	Grain consuming animal unit
GE	Gross energy
GHG	Greenhouse gas
GHMC	Ground high-moisture maize
GLA	Gamma linolenic acid
Glu	Glutamate
Gly	Glycine
GNC	Groundnut cake
GREET	Greenhouse gases, regulated emissions, and energy use in transportation
GS	Grass silage
GTAP	Global Trade Analysis Project
H⁺	Hydrogen ion
H₂S	Hydrogen sulphide
H₂S₂O₇	Thiosulphuric acid
H₂SO₃	Sulphurous acid
HC	Hemicellulose

HCHO	Formaldehyde
HCl	Hydrochloric acid
HCN	Hydrogen cyanide
His	Histidine
H-JPKM	Heated <i>Jatropha platyphylla</i> kernel meal
HMC	High moisture maize
HPDDG	High-protein dried distillers grain
HPDDGS	High-protein dried distillers grain with solubles
HRS	Hard Red Spring [wheat]
HRW	Hard Red Winter [wheat]
HS⁻	Hydrosulphide ion
HS-SH	Hydrogen persulphide
HUFA	Highly unsaturated fatty acids
ICA	Instituto Colombiano Agropecuario
ICAR	Indian Council of Agricultural Research
ICOA	International Castor Oil Association
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
Ile	Isoleucine
ILUC	Indirect land use change
IMOD	Inclusive market-oriented development
In vitro D	<i>In vitro</i> digestibility
INRA	Institut National de la Recherche Agronomique
IRR	Internal Rate of Return
IU	International Unit
IVOMD	<i>In vitro</i> organic matter digestibility
JCM	<i>Jatropha curcas</i> kernel meal
JPI	<i>Jatropha</i> protein isolate
JPKM	<i>Jatropha platyphylla</i> kernel meal
K⁺	Potassium ion
KK	Kedah-Kelantan
KLPD	Kilolitres per day
L	Lightness or luminance
LANUR	Laboratório de Nutrição de Ruminantes
LC₅₀	Lethal concentration 50 percent
LCA	Life-cycle Analysis
LD₅₀	Lethal Dose 50 [dose lethal to 50% of recipients]
LDH	Lactic dehydrogenase
LED	Light-emitting diode
Leu	Leucine
LM	Lime treated
LPC	Lupin protein concentrate
LSD	Least Significance Difference
LSF	Liquefaction, saccharification and conventional fermentation
LUC	Land use change
LW	Live weight
LWG	Liveweight gain

Lys	Lysine
MARDI	Malaysian Agricultural Research and Development Institute
masl	Metres above [mean] sea level
MDA	Malondialdehyde
MDGS	Modified distillers grain with solubles
ME	Metabolizable energy
Met	Methionine
MJ	Megajoule
MP	Metabolizable protein
MPS	Milk protein score
MS	Maize silage
MST	Mercaptopyruvate sulphurtransferase
MUFA	Mono-unsaturated fatty acids
MUN	Milk urea nitrogen
MWDGS	Modified wet distillers grain with solubles
N	Nitrogen
N₂O	Nitrous oxide
Na⁺	Sodium ion
NADPH	Nicotinamide adenine dinucleotide phosphate (reduced)
NAIP	National Agricultural Innovation Project
NaOH	Sodium hydroxide
NBB	National Biodiesel Board
NDF	Neutral-detergent fibre
NDS	Neutral-detergent solubles
NE	Net energy
NEg	Net energy for gain
NEL	Net energy for lactation
NG	Natural gas
NL	Narrow-leaf
NNP	Non-protein nitrogen
NO	Nitrous oxide
NPV	Net Present Value
NRC	National Research Council [USA]
NRCS	National Research Centre on Sorghum [India]
NREAP	National Renewable Energy Action Plan
NSC	Neem seed cake
NSKC	Neem seed kernel cake
NSP	Non-starch polysaccharide
NV	Nutritive value
O₂	Oxygen
OG	Orchardgrass
OM	Organic matter
OMD	Organic matter digestibility
OPF	Oil palm fronds
OPS	Oil palm slurry
OPT	Oil palm trunks

P	Phosphorus
Pb	Plumbum [lead]
PCV	Packed cell volume
PD	Purine derivatives
PEM	Polioencephalomalacia
PFAD	Palm fatty acid distillates
Phe	Phenylalanine
PJ	Petajoule [10^{15} joules]
PKC	Palm kernel cake
PKE	Palm kernel expeller
PKM	Palm kernel meal
PKO	Palm kernel oil
POME	Palm oil mill effluent
POS	Palm oil sludge
PPC	Potato protein concentrate
PPF	Palm press fibre
Pro	Proline
PUFA	Polyunsaturated fatty acids
PV	Peroxide value
RBC	Red blood cell
RBD	Refined Bleached De-odourized
RDP	Rumen-degradable protein
RED	Renewable Energy Directive [of the EU]
RFA	Renewable Fuels Association
RFDGS	Reduced-fat DDGS
RFS	Renewable Fuel Standard
RHMC	Rolled high-moisture maize
RIPs	Ribosome-inactivating proteins
RISDA	Rubber Industry Smallholders Development Authority
RSC	Rapeseed cake
RSM	Rapeseed meal
RUP	Ruminally undegraded crude protein
RUSBI	Rural Social Bio-refineries
S	Sulphur
S⁼	Sulphide ion
SBE	Spent bleaching earth
SBM	Soybean meal
SD	Standard deviation
SDO	Sulphur dioxygenase
SE	Solvent-extracted
SEDC	State Economic Development Corporation
Ser	Serine
SFA	Short-chain fatty acids
SFC	Steam-flaked maize
SG	Switchgrass
SGOT	Serum glutamate-oxaloacetate transaminase

SGPT	Serum glutamate-pyruvate transaminase
SH	Soybean hulls
SHF	Simultaneous hydrolysis and fermentation
SID	Standardized ileal digestibility
SKC	Solvent-extracted karanj cake
SNF	Solids not fat
SO₂	Sulphur dioxide
SOC	Soil organic carbon
SPC	Soybean protein concentrate;
SPI	Soy protein isolate
SQR	Sulphide:quinone oxidoreductase
SQR-SSH	SQR persulphide
SRC	Short-rotation coppicing
SSB	Sweet sorghum bagasse
SSF	Solid state fermentation
T1	Treatment 1
T2	Treatment 2
TAB	Treated alkali bagasse
TBARS	Thiobarbituric acid reactive substances
TDF	Total dietary fibre
TDN	Total digestible nutrients
Thr	Threonine
TJ	Terajoule [10^{12} joules]
TME	True metabolizable energy
TMP	Total milk protein
TMR	Totally mixed ration
toe	Tonne oil equivalent
Trp	Tryptophane
TS	Total solids
TSS	Total suspended solids
TVFA	Total volatile fatty acids
Tyr	Tyrosine
uCP	Utilizable crude protein at the duodenum
UFPA	Universidade Federal do Pará
UFRGS	Universidade Federal do Rio Grande do Sul
UIP	Undegradable intake protein
UMK	Universiti Malaysia Kelantan
UMMB	Urea molasses mineral blocks
UNDESA	United Nations Department of Economic and Social Affairs
UNIDO	United Nations Industrial Development Organization
UNSKC	Urea-ammoniated neem seed kernel cake
UPM	Universiti Putra Malaysia
USDA	United States Department of Agriculture
Val	Valine
VCA	Value Chain Analysis
VFA	Volatile fatty acid

WBP	Wet beet pulp
WCGF	Wet maize gluten feed
WDG	Wet distillers grain
WDGS	Wet distillers grain with solubles
WDGSH	Wet distillers grain+soy hulls blend
WPC	Whole-plant maize
WTW	Well-to-wheels
WWNSKC	Water-washed NSKC