**Upgrading plant amino acids through cattle to improve the nutritional value for humans – effects of different production systems**

*M. Patel, U. Sonesson, A. Hessle*

**Supplementary material**

*Production models*

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| **Table S1** *Age, weight at slaughter and carcass content in different beef production models in calves from a) dairy cows and b) beef cows in four systems*  |
| a) Calves from dairy cows | Reference | Intensive maize | Intensive forage | Extensive |
| Model name1 | R dairy bull I | M DxB bull I | F DxB bull I | E DxB heifer S G | E DxB heifer W G | E DxB steer S G | E DxB steer W G |
| Slaughter age, mo | 18 | 14 | 15 | 24 | 24 | 24 | 24 |
| Carcass weight, kg | 310 | 330 | 335 | 300 | 300 | 320 | 320 |
| Bone-free meat, kg | 217 | 232 | 237 | 205 | 205 | 218 | 218 |
| Offal, kg | 19 | 20 | 20 | 18 | 18 | 19 | 19 |
| Blood, kg | 19 | 20 | 20 | 18 | 18 | 19 | 19 |
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| b) Calves from beef cows | Reference | Intensive maize | Intensive forage | Extensive |
| Model name1 | R beef heifer G | R beef bull I | M beef heifer I | M beef bull I | F beef bull I | E beef heifer G | E beef steer G |
| Slaughter age, mo | 24 | 17 | 16 | 13 | 14 | 21 | 30 |
| Carcass weight, kg | 290 | 340 | 280 | 360 | 360 | 310 | 390 |
| Bone-free meat, kg | 201 | 244 | 194 | 254 | 261 | 215 | 278 |
| Offal, kg | 17 | 20 | 17 | 22 | 22 | 19 | 23 |
| Blood, kg | 17 | 20 | 17 | 22 | 22 | 19 | 23 |
| 1 R = Reference; M = Intensive maize; F = Intensive forage; E = Extensive; D x B = dairy x beef crossbred; S = summer; W = winter (season of birth); G = grazing; I = indoor. |

*Feeds and feed rations*

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| **Table S2** *Annual feed consumption per head in different dairy production systems: Reference, R9000; Intensive maize and beans, M11000; Intensive food industry by-products, F11000; Extensive, E7000. Feed consumption forreplacement heifers is summarized for 27 months of rearing*  |
| System | R9000 | M11000 | F11000 | E7000 | Heifer |
| Reference grass/clover silage, kg DM1 | 2767 |  |  |  | 2527 |
| Maize silage, kg DM |  | 514 |  |  |  |
| Clover silage, kg DM |  |  | 3473 | 3805 |  |
| Grass silage, kg DM |  | 3390 |  |  |  |
| Cultivated pasture, kg DM | 660 | 208 | 492 | 549 |  |
| Semi-natural pasture, kg DM |  |  |  |  | 1740 |
| Cereal grain, kg2 | 1620 | 1548 | 1376 | 665 | 236 |
| Commercial concentrate, kg3 | 1196 |  |  |  | 71 |
| Field beans, kg |  | 527 |  |  |  |
| Rapeseed meal, kg |  | 332 | 286 |  |  |
| Rapeseed cake, kg |  | 58 | 442 | 381 |  |
| Beet fibre, kg | 275 | 336 | 412 |  |  |
| Wheat bran, kg |  |  | 580 |  |  |
| Distiller’s grains, kg |  |  | 214 |  |  |
| Whole milk, kg |  |  |  |  | 250 |
| Mineral supplement, kg4 | 35 | 40 | 40 | 25 | 25 |
| 1 DM = dry matter.2 1/3 each of barley, wheat and oats.3 Contained 50% rapeseed meal, 30% wheat middlings and 20% beet fibre4 Contained 132 g Ca and 138 g P/kg DM. |

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| **Table S3** *Feed consumption per head of slaughtered beef cattle from dairy cows in different production models in four different systems* |
|  | Reference | Intensive maize | Intensive forage | Extensive |
| Model name1 | R dairy bull I | M DxB bull I | F DxB bull I | E DxB heifer S G | E DxB heifer W G | E DxB steer S G | E DxB steer W G |
| Reference silage early harvest, kg DM2 | 1537 | - | - | - | - | - | - |
| Grass silage, kg DM | - | - | 1789 | 2433 | 2307 | 2431 | 2548 |
| Maize silage, kg DM | - | 869 | - | - | - | - | - |
| Clover silage, kg DM | - | 848 | - | - | - | - | - |
| Semi-natural pastures, kg DM | - | - | - | 1716 | 1980 | 2083 | 2343 |
| Cereal grain, kg3 | 1842 | 1168 | 1240 | 228 | 180 | 227 | 182 |
| Commercial concentrate, kg | 173 | - | - | - | - | - | - |
| Field beans, kg | - | 193 | 115 | 171 | 101 | 172 | 100 |
| Rapeseed cake, kg | - | 118 | 66 | 50 | 14 | 50 | 14 |
| Mineral supplement, kg | 30 | 46 | 62 | 17 | 22 | 24 | 26 |
| Whole milk, kg | 150 | 250 | 250 | 250 | 250 | 250 | 250 |
| Milk replacer, kg powder | 25 | - | - | - | - | - | - |
| 1 R = Reference; M = Intensive maize; F = Intensive forage; E = Extensive; D x B = dairy x beef crossbred; S = summer; W = winter (season of birth); G = grazing; I = indoor.2 DM = dry matter.3 1/3 each of barley, wheat and oats. |

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| **Table S4** *Feed consumption per head of slaughtered beef cattle from suckler production in different production models in four different systems* |
|  | Reference | Intensive maize | Intensive forage | Extensive |
| Model name1 | R beef heifer G | R beef bull I | M beef heifer I | M beef bull I | F beef bull I | E beef heifer G | E beef steer G |
| Reference silage early harvest, kg DM2 | 2299 | 1108 | - | - | - | - | 3076 |
| Grass silage, kg DM | - | - | - | - | 1191 | 1773 | - |
| Maize silage, kg DM | - | - | 998 | 553 | - | - | - |
| Clover silage, kg DM | - | - | 998 | 553 | - | - | - |
| Semi-natural pastures, kg DM | 1057 | - | - | - | - | 1360 | 2594 |
| Cereal grain, kg3 | 91 | 1431 | 523 | 894 | 890 | - | - |
| Field beans, kg | - | - | 77 | 52 | - | - | - |
| Rapeseed cake, kg | - | - | 43 | 17 | - | - | - |
| Mineral supplement4, kg | 25 | 32 | 7 | 35 | 37 | 9 | 14 |
| 1 R = Reference; M = Intensive maize; F = Intensive forage; E = Extensive; S = summer; W = winter (season of birth); G = grazing; I = indoor. 2 DM = dry matter.3 1/3 each of barley, wheat and oats.4 Contained 72-170 g Ca and 10-92 g P/kg DM. |

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| **Table S5** *Annual feed consumption per suckler cow and breeding bull and per replacement heifer reared in suckler production in four different systems* |
|  | Reference | Intensive maize, Intensive forage and Extensive |
|  | Suckler cow | Breeding bull | Replacement heifer | Suckler cow | Breeding bull | Replacement heifer |
| Reference silage early harvest, kg DM1 | - | - | 2299 | - | - | 2299 |
| Reference silage late harvest, kg DM | 1684 | 2410 | - | 878 | 2410 | - |
| Reed canary grass silage, kg DM | - | - | - | 683 | - | - |
| Semi-natural pastures, kg DM | 2257 | 1887 | 1057 | 3081 | 1887 | 1057 |
| Cereal grain, kg2 | - | - | 91 | 303 | - | 91 |
| Field beans, kg | - | - | - | 103 | - | - |
| Mineral supplements, kg | 22 | 72 | 25 | 37 | 72 | 25 |
| 1 DM = dry matter.2 1/3 each of barley, wheat and oats.3 creep feeding to the suckling calf. |

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| **Table S6** *Chemical composition (g/kg of dry matter, DM) of forages* |
|  | Reference grass/clover silage, early harvest | Reference grass/clover silage, late harvest | Clover silage | Grass silage | Maize silage | Reed canary grass silage | Cultivated pasture | Semi-natural pasture |
| ME1, MJ | 10.6 | 9.9 | 10.6 | 11.4 | 11.0 | 7.4 | 11.0 | 9.4 |
| CP2 | 141 | 96 | 168 | 149 | 91 | 115 | 147 | 130 |
| Starch | - | - | - | - | 223 | - | - | - |
| NDF3 | 573 | 585 | 546 | 520 | 496 | 687 | 480 | 550 |
| Crude fat | 20 | 20 | 20 | 20 | 22 | 20 | 20 | 20 |
| Ca | 6 | 3.4 | 7.8 | 8.0 | 2.4 | 4.4 | 8.0 | 4.1 |
| P | 2.7 | 1.8 | 2.7 | 2.7 | 2.3 | 2.3 | 2.7 | 2.8 |
| K | 22.0 | 13.0 | 21.3 | 22.8 | 10.1 | 5.4 | 24.0 | 22.0 |
| Ash | 74 | 80 | 74 | 73 | 44 | 40 | 74 | 66 |
| 1 ME = metabolisable energy. |

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| **Table S7** *Chemical composition (g/kg DM, dry matter) of concentrates* |
|  | Cereal grain | Rape seed meal | Rape seed cake | Beet fibre | Field bean | Wheat bran | Distiller’s grains  |
| DM, % | 87 | 87 | 94 | 91 | 87 | 87 | 90 |
| ME1, MJ | 13.1 | 12.1 | 15.5 | 12.5 | 12.9 | 11.0 | 13.3 |
| CP | 123 | 384 | 339 | 105 | 302 | 160 | 320 |
| Starch | 560 | 90 | 87 | 0 | 420 | 210 | 0 |
| NDF | 246 | 100 | 311 | 334 | 160 | 464 | 270 |
| Crude fat | 30 | 67 | 169 | 0 | 15 | 45 | 45 |
| Ca | 0.4 | 8 | 7.5 | 9.5 | 4 | 1.7 | 2.6 |
| P | 4.0 | 13.4 | 12.4 | 0.7 | 5.6 | 12.0 | 10.3 |
| K | 5.1 | 15.2 | 13.2 | 18.5 | 9.1 | 12.0 | 13.7 |
| Ash | 28 | 79 | 66 | 86 | 60 | 60 | 37 |
| 1 ME = metabolisable energy. |

| **Table S8** *Description of suckler production in four systems* |
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|    | Reference | Intensive maize, Intensive forage and Extensive |
| Breed  | Cross-bred beef  | Cross-bred beef  |
| Replacement, % | 20 | 20 |
| Calves born live, number per mated cow and year | 0.858 | 0.858 |
| Mortality of cows, % | 2.0 | 0.9 |
| Mortality of heifer calves, % | 5.1 | 1.5 |
| Mortality of bull calves, % | 6.3 | 1.9 |
| Carcass weight cows, kg | 375 | 375 |
| Bone-free meat cows, kg | 252 | 252 |
|  |  |  |
| Offal cows, kg | 22 | 22 |
| Blood cows, kg | 22 | 22 |
| Carcass weight breeding bulls, kg | 550 | 550 |
| Bone-free meat breeding bulls, kg | 405 | 405 |
| Offal breeding bulls, kg | 33 | 33 |
| Blood breeding bulls, kg | 33 | 33 |

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| **Table S9** *Added feed consumption for different production models of beef cattle from suckler production due to their parents’ feed consumption* |
| Model1 | Extra feed, % |
|  | Cow | Breeding bull | Replacement heifer |
| R beef heifer G | 132 | 5 | 20 |
| R beef bull I | 137 | 5 | 20 |
| M beef heifer I | 121 | 5 | 20 |
| M beef bull I | 122 | 5 | 20 |
| F beef heifer G | 121 | 5 | 20 |
| F beef bull I | 122 | 5 | 20 |
| E beef heifer G | 121 | 5 | 20 |
| E beef steer G | 122 | 5 | 20 |
| 1 R = Reference; M = Intensive maize; F = Intensive forage; E = Extensive; G = grazing; I = indoor.  |

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| **Table S10** *Amino acid composition (g/ kg CP) of the different concentrate feeds (CVB, 2011)* |
|  | *CP g/kg DM* | *Ala*  | *Arg*  | *Asp* | *Cys*  | *Glu*  | *Gly*  | *His*  | *Ile* | *Leu*  | *Lys*  | *Met*  | *Phe*  | *Pro* | *Ser*  | *Thr*  | *Trp* | *Tyr*  | *Val* |
| Cereal grain1 | 123 | 42 | 54 | 65 | 25 | 237 | 43 | 22 | 35 | 69 | 35 | 17 | 48 | 86 | 45 | 33 | 12 | 31 | 48 |
| Commercial concentrate | 290 | 45 | 56 | 83 | 21 | 163 | 48 | 26 | 35 | 62 | 41 | 17 | 38 | 56 | 42 | 39 | 12 | 31 | 48 |
| Field bean | 302 | 41 | 91 | 109 | 13 | 164 | 42 | 26 | 41 | 73 | 63 | 8 | 41 | 43 | 48 | 35 | 9 | 33 | 45 |
| Rapeseed meal | 384 | 45 | 61 | 75 | 25 | 169 | 52 | 28 | 39 | 70 | 44 | 20 | 41 | 60 | 44 | 44 | 13 | 31 | 51 |
| Rapeseed cake | 339 | 45 | 61 | 75 | 25 | 169 | 52 | 28 | 39 | 70 | 55 | 20 | 41 | 60 | 44 | 44 | 13 | 31 | 51 |
| Beet fibre | 105 | 42 | 29 | 121 | 9 | 102 | 32 | 21 | 27 | 43 | 36 | 11 | 27 | 30 | 36 | 35 | 6 | 34 | 44 |
| Wheat bran | 160 | 47 | 67 | 71 | 21 | 194 | 51 | 27 | 32 | 62 | 40 | 16 | 40 | 65 | 44 | 33 | 14 | 29 | 47 |
| Distiller’s grain  | 320 | 43 | 40 | 54 | 17 | 237 | 39 | 20 | 36 | 75 | 21 | 15 | 45 | 85 | 44 | 32 | 9 | 0 | 43 |
| Ala = alanine; Arg = arginine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; His = histidine; Ile = Isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylalanine; Pro = proline; Ser = serine; Thr = threonine; Trp = tryptophan; Tyr = tyrosine; Val = valine.11/3 each of barley, wheat and oats. |

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| **Table S11** *True ileal digestibility in pigs (%) of amino acids in concentrate feeds (CVB, 2011)* |
|  | Ala | Arg | Asp | Cys | Glu | Gly | His | Ile | Leu | Lys | Met | Phe | Pro | Ser | Thr | Trp | Tyr | Val |
| Cereal grain1 | 77 | 88 | 78 | 82 | 90 | 80 | 87 | 85 | 85 | 80 | 85 | 87 | 91 | 86 | 80 | 81 | 86 | 83 |
| Commercial concentrate | 70 | 79 | 64 | 68 | 80 | 69 | 76 | 71 | 73 | 71 | 77 | 71 | 76 | 69 | 63 | 70 | 72 | 68 |
| Field bean | 82 | 94 | 87 | 72 | 92 | 84 | 88 | 86 | 87 | 89 | 86 | 79 | 88 | 89 | 83 | 76 | 78 | 85 |
| Rapeseed cake/meal | 76 | 84 | 71 | 70 | 84 | 74 | 80 | 75 | 77 | 74 | 81 | 77 | 80 | 76 | 71 | 71 | 75 | 72 |
| Beet fibre | 47 | 53 | 26 | 46 | 58 | 45 | 52 | 51 | 52 | 55 | 59 | 46 | 45 | 33 | 28 | 50 | 52 | 42 |
| Wheat bran | 58 | 87 | 66 | 72 | 83 | 67 | 79 | 67 | 70 | 68 | 73 | 60 | 86 | 72 | 60 | 75 | 68 | 65 |
| Distiller’s grain | 75 | 86 | 74 | 80 | 89 | 76 | 78 | 81 | 84 | 63 | 85 | 88 | 88 | 83 | 77 | 79 | 86 | 78 |
| Ala = alanine; Arg = arginine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; His = histidine; Ile = Isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylalanine; Pro = proline; Ser = serine; Thr = threonine; Trp = tryptophan; Tyr = tyrosine; Val = valine.11/3 each of barley, wheat and oats. |

*Animal products*

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| **Table S12** *Amino acid composition (g/kg product) in animal products from cattle (USDA, 2014)*  |
|  | *Ala*  | *Arg*  | *Asp* | *Cys*  | *Glu*  | *Gly*  | *His*  | *Ile* | *Leu*  | *Lys*  | *Met*  | *Phe*  | *Pro* | *Ser*  | *Thr*  | *Trp* | *Tyr*  | *Val* |
| Milk | 1.1 | 0.9 | 2.7 | 0.2 | 7.1 | 0.6 | 1.0 | 1.6 | 3.0 | 2.6 | 0.8 | 1.6 | 3.1 | 1.9 | 1.3 | 0.4 | 1.6 | 2.1 |
| Bone- free meat | 14.2 | 14.8 | 20.4 | 2.7 | 33.6 | 15.1 | 7.1 | 9.9 | 17.6 | 18.8 | 5.7 | 8.8 | 11.5 | 9.0 | 9.1 | 1.5 | 7.0 | 11.0 |
| Offal | 10.2 | 11.5 | 16.8 | 2.8 | 24.4 | 10.4 | 5.8 | 8.2 | 15.6 | 14.4 | 5.1 | 8.6 | 7.8 | 7.5 | 7.5 | 2.1 | 6.7 | 10.0 |
| Blood | 9.4 | 5.1 | 13.0 | 1.4 | 10.9 | 5.3 | 7.5 | 1.4 | 15.1 | 10.5 | 1.4 | 8.1 | 4.6 | 5.9 | 5.2 | 1.8 | 3.4 | 10.1 |
| Ala = alanine; Arg = arginine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; His = histidine; Ile = Isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylalanine; Pro = proline; Ser = serine; Thr = threonine; Trp = tryptophan; Tyr = tyrosine; Val = valine. |

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| **Table S13** *True ileal digestibility in pigs (%) of amino acids in animal products from cattle (CVB, 2011)*  |
|  | *Ala*  | *Arg*  | *Asp* | *Cys*  | *Glu*  | *Gly*  | *His*  | *Ile* | *Leu*  | *Lys*  | *Met*  | *Phe*  | *Pro* | *Ser*  | *Thr*  | *Trp* | *Tyr*  | *Val* |
| Milk  | 89 | 97 | 93 | 91 | 88 | 95 | 96 | 88 | 96 | 96 | 96 | 97 | 99 | 81 | 92 | 91 | 97 | 89 |
| Bone-free meat, offal and blood | 88 | 95 | 88 | 88 | 88 | 88 | 93 | 75 | 88 | 94 | 88 | 92 | 88 | 88 | 88 | 91 | 93 | 88 |
| Ala = alanine; Arg = arginine; Asp = aspartic acid; Cys = cystine; Glu = glutamic acid; Gly = glycine; His = histidine; Ile = Isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylalanine; Pro = proline; Ser = serine; Thr = threonine; Trp = tryptophan; Tyr = tyrosine; Val = valine. |

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| **Table S14** *Composition and source of animal products when calculating contents of protein and amino acids in milk, bone-free meat, offal and blood (CVB, 2011; USDA, 2014)* |
| Animal product | Based on | Reference | Proportion of product, % |
| Milk | Milk | USDA no 01077 | 100 |
| Bone-free meat | Steaks, lean1 | USDA no 13364 | 36 |
|  | Ground beef, lean | USDA no 23557 | 36 |
|  | Cured beef1 | USDA no 13360 | 28 |
| Offal | Liver | USDA no 13325 | 49 |
|  | Tongue | USDA no 13339 | 17 |
|  | Heart | USDA no 23415 | 17 |
|  | Kidney | USDA no 23423 | 17 |
| Blood | Blood2 | CVB blood meal | 100 |
| 1 Available data on cooked meat multiplied by a factor of 0.8 to correct for cooking losses of water. 2 Available data on blood meal multiplied by a factor of 0.127 to correct for drying losses of water. |

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| ***Table S15*** *Explanatory table1 showing annual crude protein and human-edible essential amino acid (EAA) inputs in feed rations for dairy cows, including replacement heifer, outputs in the form of milk and meat (from the culled cow) and EAA efficiency in the reference milk production system: R9000* |
|  |  |  | Human-edible essential amino acids, kg |
| Item | Crudeprotein, kg | % human digestible protein2 | His | Ile | Leu | Lys | MetCys | PheTyr | Thr | Trp | Val |
| *Input* |  |  |  |  |  |  |  |  |  |  |  |
| R9000 | 1194 | 31 | 7.46 | 9.27 | 17.01 | 11.21 | 9.98 | 18.63 | 9.09 | 3.07 | 12.35 |
|  |  |  |  |  |  |  |  |  |  |  |  |
| *Output* |  |  |  |  |  |  |  |  |  |  |  |
| Milk |  |  |  |  |  |  |  |  |  |  |  |
| R9000 | 293 | 93 | 7.86 | 12.36 | 24.74 | 21.84 | 8.36 | 26.92 | 10.62 | 3.14 | 15.80 |
|  |  |  |  |  |  |  |  |  |  |  |  |
| Bone-free meat, offal, blood |  |  |  |  |  |  |  |  |  |  |  |
| R9000 | 20 | 86 | 0.57 | 0.74 | 1.40 | 1.45 | 0.64 | 1.25 | 0.70 | 0.12 | 0.88 |
|  |  |  |  |  |  |  |  |  |  |  |  |
| *output/input* |  |  |  |  |  |  |  |  |  |  |  |
| R9000 |  |  | 1.13 | 1.41 | 1.54 | 2.08 | 0.90 | 1.51 | 1.25 | 1.06 | 1.35 |
| His = histidine; Ile = Isoleucine; Leu = leucine; Lys = lysine; MetCys = methionine + cystine; PheTyr = phenylalanine + tyrosine; Thr = threonine; Trp = tryptophan; Val = valine.1Calculations of EAA input were performed as: kg feed × (g CP/kg DM × g amino acid/kg CP × 10-6) × EAA digestibility %, all variables are found in Tables S2, S10, S11. Likewise were the calculations of EAA output performed using variables found in Tables S12, S13 and in the original paper Table 1. Beef production systems were calculated similarly using variables found in Tables S1, S3, S4, S5, S7, S10, S11, S12, S13.2CAST (1999). |

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| **Table S16** *Amino acid efficiency in different dairy production systems: Reference. R9000; Intensive maize and beans. M11000; Intensive food industry by-products. F11000; Extensive. E7000. Ratio of output of individual human-digestible amino acids in animal products/input of human-digestible amino acids in feeds. Values >1 indicate higher output than input of digestible amino acids. Annual milk production. meat from culled cows and feed for rearing heifers included* |
| System | R9000 | M11000 | F11000 | E7000 |
| Alanine | 0.50 | 0.63 | 0.54 | 0.95 |
| Arginine | 0.53 | 0.47 | 0.47 | 0.96 |
| Aspartic acid | 1.17 | 1.14 | 1.23 | 2.48 |
| Glutamic acid | 1.15 | 1.40 | 0.97 | 2.27 |
| Glycine | 0.51 | 0.62 | 0.46 | 0.90 |
| Histidine | 1.13 | 1.35 | 1.06 | 2.15 |
| Isoleucine | 1.41 | 1.48 | 1.27 | 2.56 |
| Leucine | 1.54 | 1.63 | 1.32 | 2.77 |
| Lysine | 2.08 | 1.87 | 1.95 | 3.26 |
| Methionine + Cystine | 0.90 | 1.32 | 0.79 | 1.53 |
| Phenylalanine + Tyrosine | 1.51 | 1.79 | 1.48 | 2.93 |
| Proline | 1.76 | 2.34 | 1.38 | 3.26 |
| Serine | 1.28 | 1.35 | 1.13 | 2.39 |
| Threonine | 1.25 | 1.39 | 1.11 | 2.08 |
| Tryptophan | 1.06 | 1.49 | 0.97 | 2.03 |
| Valine | 1.35 | 1.60 | 1.27 | 2.59 |

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| **Table S17** *Amino acid efficiency in beef cattle from dairy cows in different production models in four systems. Ratio of output of individual human-digestible amino acids in animal products/input of human-digestible amino acids in feeds. Values >1 indicate higher output than input of digestible amino acids* |
|  | Reference |  | Intensive maize |  | Intensive forage |  | Extensive |
| Model name1 | R dairy bull I |  | M DxB bull I |  | F DxB bull I |  | E DxB heiferS G | E DxB heifer W G | E DxB steerS G | E DxB steerW G |
| Alanine | 0.39 |  | 0.44 |  | 0.52 |  | 0.88 | 1.42 | 0.93 | 1.52 |
| Arginine | 0.34 |  | 0.28 |  | 0.36 |  | 0.50 | 0.83 | 0.53 | 0.89 |
| Aspartic acid | 0.28 |  | 0.25 |  | 0.31 |  | 0.42 | 0.67 | 0.44 | 0.71 |
| Glutamic acid | 0.15 |  | 0.17 |  | 0.20 |  | 0.38 | 0.59 | 0.41 | 0.63 |
| Glycine | 0.40 |  | 0.42 |  | 0.50 |  | 0.86 | 1.43 | 0.91 | 1.53 |
| Histidine | 0.36 |  | 0.35 |  | 0.43 |  | 0.67 | 1.07 | 0.71 | 1.14 |
| Isoleucine | 0.30 |  | 0.31 |  | 0.37 |  | 0.58 | 0.91 | 0.62 | 0.98 |
| Leucine | 0.29 |  | 0.31 |  | 0.37 |  | 0.59 | 0.92 | 0.63 | 0.99 |
| Lysine | 0.59 |  | 0.48 |  | 0.62 |  | 0.78 | 1.23 | 0.83 | 1.32 |
| Methionine + Cystine | 0.21 |  | 0.25 |  | 0.29 |  | 0.61 | 0.96 | 0.65 | 1.02 |
| Phenylalanine + Tyrosine | 0.22 |  | 0.26 |  | 0.30 |  | 0.53 | 0.80 | 0.56 | 0.86 |
| Proline | 0.15 |  | 0.19 |  | 0.21 |  | 0.44 | 0.65 | 0.47 | 0.69 |
| Serine | 0.21 |  | 0.22 |  | 0.26 |  | 0.43 | 0.67 | 0.46 | 0.72 |
| Threonine | 0.30 |  | 0.31 |  | 0.38 |  | 0.60 | 0.96 | 0.64 | 1.02 |
| Tryptophan | 0.15 |  | 0.17 |  | 0.20 |  | 0.38 | 0.59 | 0.40 | 0.63 |
| Valine | 0.26 |  | 0.29 |  | 0.34 |  | 0.57 | 0.89 | 0.61 | 0.95 |
| 1 R = Reference; M = Intensive maize; F = Intensive forage; E = Extensive; D x B = dairy x beef crossbred; S = summer; W = winter (season of birth); G = grazing; I = indoor. |

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| **Table S18** *Amino acid efficiency in beef cattle from suckler production in different production models in four systems. Ratio of output of individual human-digestible amino acids in animal products/input of human-digestible amino acids in feeds. Values >1 indicate higher output than input of digestible amino acids. Inputs and outputs from culled parents are included* |
|  | Reference |  | Intensive maize |  | Intensive forage |  | Extensive |
| Model name1 | R beef heifer G | R beef bull I |  | M beef heifer I | M beef bull I |  | F beef bull I |  | E beef heifer G | E beef steer G |
| Alanine | 10.52 | 0.91 |  | 1.10 | 1.11 |  | 1.48 |  | 22.19 | 26.93 |
| Arginine | 8.06 | 0.70 |  | 0.71 | 0.77 |  | 1.13 |  | 17.01 | 20.65 |
| Aspartic acid | 7.29 | 0.63 |  | 0.64 | 0.69 |  | 1.02 |  | 15.37 | 18.66 |
| Glutamic acid | 3.57 | 0.31 |  | 0.44 | 0.41 |  | 0.50 |  | 7.54 | 9.15 |
| Glycine | 9.99 | 0.87 |  | 1.04 | 1.05 |  | 1.40 |  | 21.07 | 25.58 |
| Histidine | 9.15 | 0.79 |  | 0.91 | 0.94 |  | 1.28 |  | 19.31 | 23.43 |
| Isoleucine | 7.78 | 0.67 |  | 0.80 | 0.81 |  | 1.09 |  | 16.41 | 19.92 |
| Leucine | 7.48 | 0.65 |  | 0.80 | 0.79 |  | 1.05 |  | 15.79 | 19.16 |
| Lysine | 16.03 | 1.39 |  | 1.29 | 1.45 |  | 2.25 |  | 33.83 | 41.05 |
| Methionine + Cystine | 5.09 | 0.44 |  | 0.63 | 0.59 |  | 0.72 |  | 10.75 | 13.04 |
| Phenylalanine + Tyrosine | 5.73 | 0.50 |  | 0.66 | 0.64 |  | 0.80 |  | 12.09 | 14.67 |
| Proline | 3.63 | 0.32 |  | 0.48 | 0.43 |  | 0.51 |  | 7.66 | 9.30 |
| Serine | 5.29 | 0.46 |  | 0.56 | 0.56 |  | 0.74 |  | 11.15 | 13.53 |
| Threonine | 7.91 | 0.69 |  | 0.80 | 0.82 |  | 1.11 |  | 16.69 | 20.25 |
| Tryptophan | 3.78 | 0.33 |  | 0.44 | 0.42 |  | 0.53 |  | 7.98 | 9.68 |
| Valine | 6.75 | 0.59 |  | 0.74 | 0.73 |  | 0.95 |  | 14.24 | 17.28 |
| 1 R = Reference; M = Intensive maize; F = Intensive forage; E = Extensive; G = grazing; I = indoor. |

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| **Table S19** *Sensitivity analysis for balance of net quantities of digestible amino acids in human-edible feeds and in milk and meat per year in two dairy production systems. Feed consumption was originally included as a parameter. but excluded since it showed the same results as feed digestibility. Values above zero indicate higher output than input. i.e. higher quantity of a particular amino acid in food than in human-edible feed consumed by the animal* |
| Model name1 | F11000 |  | E7000 |
|  | Base2 | Feed digestibility | Animal product digestibility |  | Base2 | Feed digestibility | Animal product digestibility |
|  |  | -10% | +10% | -10% | +10% |  |  | -10% | +10% | -10% | +10% |
| Alanine | -9.46 | -7.39 | -11.54 | -10.59 | -8.33 |  | -0.35 | 0.39 | -1.10 | -1.06 | 0.35 |
| Arginine | -11.75 | -9.53 | -13.97 | -12.80 | -11.34 |  | -0.30 | 0.39 | -0.98 | -0.95 | -0.05 |
| Aspartic acid | 5.18 | 7.48 | 2.89 | 2.36 | 7.35 |  | 10.67 | 11.39 | 9.95 | 8.88 | 12.04 |
| Cystine | -5.14 | -4.42 | -5.86 | -5.35 | -4.94 |  | -1.04 | -0.81 | -1.27 | -1.17 | -0.91 |
| Glutamic acid | -2.31 | 4.75 | -9.38 | -9.15 | 4.52 |  | 24.39 | 26.31 | 22.47 | 20.03 | 28.75 |
| Glycine | -8.66 | -7.04 | -10.27 | -9.41 | -8.20 |  | -0.49 | 0.02 | -1.01 | -0.96 | -0.22 |
| Histidine | 0.62 | 1.58 | -0.33 | -0.40 | 1.09 |  | 3.47 | 3.78 | 3.17 | 2.82 | 3.76 |
| Isoleucine | 3.36 | 4.62 | 2.11 | 1.77 | 4.96 |  | 6.17 | 6.57 | 5.78 | 5.16 | 7.19 |
| Leucine | 7.73 | 10.13 | 5.35 | 4.56 | 9.15 |  | 12.92 | 13.65 | 12.20 | 10.90 | 13.81 |
| Lysine | 13.78 | 15.23 | 12.35 | 10.95 | 15.06 |  | 12.47 | 13.02 | 11.92 | 10.67 | 13.26 |
| Methionine | 2.22 | 2.89 | 1.56 | 1.33 | 2.62 |  | 3.45 | 3.67 | 3.24 | 2.89 | 3.70 |
| Phenylalanine | 3.33 | 4.74 | 1.93 | 1.59 | 3.93 |  | 6.83 | 7.26 | 6.41 | 5.72 | 7.20 |
| Proline | 9.25 | 11.66 | 6.87 | 5.92 | 9.68 |  | 14.79 | 15.44 | 14.15 | 12.65 | 15.05 |
| Serine | 1.91 | 3.41 | 0.40 | 0.21 | 3.60 |  | 6.29 | 6.75 | 5.84 | 5.21 | 7.37 |
| Threonine | 1.34 | 2.58 | 0.10 | -0.03 | 2.55 |  | 4.54 | 4.96 | 4.12 | 3.67 | 5.31 |
| Tryptophan | -0.14 | 0.27 | -0.55 | -0.53 | 0.26 |  | 1.29 | 1.41 | 1.16 | 1.03 | 1.54 |
| Tyrosine | 7.82 | 8.72 | 6.93 | 6.13 | 8.38 |  | 7.57 | 7.89 | 7.26 | 6.49 | 7.92 |
| Valine | 4.30 | 5.90 | 2.71 | 2.28 | 6.33 |  | 7.93 | 8.43 | 7.43 | 6.64 | 9.22 |
| 1 F11000 = intensive dairy production based on food industry by-products; E7000 = extensive dairy production based on forage.2Base = balance of amino acid output – input in the original calculations. |

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| **Table S20** *Sensitivity analysis for balance of net quantities of digestible amino acids in human-edible feeds and in meat per year in two systems of beef production from dairy cows. Feed consumption was originally included as a parameter. but excluded since it showed the same results as feed digestibility. Values above zero indicate higher output than input. i.e. higher quantity of a particular amino acid in food than in human-edible feed consumed by the animal* |
| Model name1 | E DxB heifer W G |  | F DxB bull I |
|  | Base2 | Feed digestibility | Animal product digestibility |  | Base2 | Feed digestibility | Animal product digestibility |
|  |  | -10% | +10% | -10% | +10% |  |  | -10% | +10% | -10% | +10% |
| Alanine | 0.75 | 0.93 | 0.58 | 0.50 | 1.01 |  | -2.65 | -2.09 | -3.21 | -2.94 | -2.36 |
| Arginine | -0.57 | -0.23 | -0.90 | -0.86 | -0.29 |  | -5.86 | -4.94 | -6.75 | -6.18 | -5.53 |
| Aspartic acid | -1.37 | -0.96 | -1.77 | -1.65 | -1.10 |  | -7.05 | -6.03 | -8.06 | -7.37 | -6.73 |
| Cystine | -0.37 | -0.30 | -0.44 | -0.40 | -0.34 |  | -2.62 | -2.32 | -2.92 | -2.66 | -2.58 |
| Glutamic acid | -3.90 | -2.95 | -4.86 | -4.47 | -3.34 |  | -26.54 | -23.23 | -29.85 | -27.19 | -25.89 |
| Glycine | 0.77 | 0.95 | 0.60 | 0.51 | 1.02 |  | -2.90 | -2.32 | -3.48 | -3.20 | -2.61 |
| Histidine | 0.08 | 0.21 | -0.02 | -0.05 | 0.21 |  | -2.00 | -1.65 | -2.34 | -2.16 | -1.86 |
| Isoleucine | -0.16 | 0.03 | -0.35 | -0.33 | 0.01 |  | -3.37 | -2.83 | -3.90 | -3.57 | -3.17 |
| Leucine | -0.27 | 0.09 | -0.58 | -0.60 | 0.05 |  | -6.53 | -5.50 | -7.52 | -6.91 | -6.16 |
| Lysine | 0.63 | 0.90 | 0.40 | 0.30 | 0.96 |  | -2.40 | -1.77 | -2.99 | -2.79 | -2.02 |
| Methionine | 0.32 | 0.39 | 0.26 | 0.22 | 0.42 |  | -1.21 | -0.97 | -1.43 | -1.32 | -1.09 |
| Phenylalanine | -0.39 | -0.19 | -0.57 | -0.56 | -0.23 |  | -4.81 | -4.14 | -5.46 | -5.00 | -4.62 |
| Proline | -1.13 | -0.80 | -1.38 | -1.34 | -0.92 |  | -9.30 | -8.13 | -10.41 | -9.54 | -9.06 |
| Serine | -0.74 | -0.51 | -0.96 | -0.89 | -0.59 |  | -4.94 | -4.27 | -5.61 | -5.12 | -4.77 |
| Threonine | -0.07 | 0.10 | -0.22 | -0.22 | 0.09 |  | -2.98 | -2.50 | -3.45 | -3.16 | -2.80 |
| Tryptophan | -0.19 | -0.14 | -0.24 | -0.22 | -0.16 |  | -1.26 | -1.10 | -1.42 | -1.29 | -1.23 |
| Tyrosine | -0.32 | -0.16 | -0.45 | -0.44 | -0.19 |  | -3.17 | -2.70 | -3.60 | -3.31 | -3.02 |
| Valine | -0.24 | -0.02 | -0.47 | -0.44 | -0.05 |  | -4.52 | -3.83 | -5.20 | -4.75 | -4.29 |
| 1 E = Extensive; F = Intensive forage; D x B = dairy x beef crossbred; W = winterborn; G = Grazing; I = indoor.2Base = balance of amino acid output – input in the original calculations. |

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| **Table S21** *Sensitivity analysis for balance of net quantities of digestible amino acids in human-edible feeds and in meat per year in two systems of beef production from suckler cows. Feed consumption was originally included as a parameter. but excluded since it showed the same results as feed digestibility. Values above zero indicate higher output than input. i.e. higher quantity of a particular amino acid in food than in human-edible feed consumed by the animal* |
| Model name1 | E beef heifer G |  | M beef bull I |
|  | Base2 | Feed digestibility | Animal product digestibility |  | Base2 | Feed digestibility | Animal product digestibility |
|  |  | -10% | +10% | -10% | +10% |  |  | -10% | +10% | -10% | +10% |
| Alanine | 3.44 | 3.46 | 3.43 | 3.08 | 3.81 |  | 0.41 | 0.78 | 0.05 | 0.01 | 0.82 |
| Arginine | 3.82 | 3.85 | 3.80 | 3.42 | 4.22 |  | -1.40 | -0.80 | -2.00 | -1.86 | -0.94 |
| Aspartic acid | 3.66 | 3.69 | 3.64 | 3.27 | 4.05 |  | -2.01 | -1.36 | -2.65 | -2.45 | -1.56 |
| Cystine | 0.36 | 0.37 | 0.35 | 0.31 | 0.40 |  | -1.57 | -1.36 | -1.78 | -1.62 | -1.52 |
| Glutamic acid | 7.01 | 7.11 | 6.90 | 6.20 | 7.81 |  | -13.19 | -10.95 | -15.42 | -14.10 | -12.27 |
| Glycine | 3.47 | 3.49 | 3.45 | 3.11 | 3.83 |  | 0.21 | 0.60 | -0.18 | -0.20 | 0.62 |
| Histidine | 1.76 | 1.77 | 1.75 | 1.58 | 1.94 |  | -0.14 | 0.09 | -0.36 | -0.35 | 0.06 |
| Isoleucine | 2.30 | 2.32 | 2.29 | 2.06 | 2.55 |  | -0.65 | -0.31 | -0.99 | -0.93 | -0.37 |
| Leucine | 4.36 | 4.39 | 4.33 | 3.89 | 4.82 |  | -1.36 | -0.70 | -2.02 | -1.89 | -0.84 |
| Lysine | 4.62 | 4.63 | 4.61 | 4.14 | 5.09 |  | 1.67 | 2.05 | 1.30 | 1.14 | 2.20 |
| Methionine | 1.35 | 1.36 | 1.35 | 1.21 | 1.50 |  | 0.10 | 0.25 | -0.05 | -0.06 | 0.26 |
| Phenylalanine | 2.14 | 2.16 | 2.12 | 1.90 | 2.37 |  | -1.79 | -1.35 | -2.24 | -2.06 | -1.53 |
| Proline | 2.62 | 2.66 | 2.58 | 2.32 | 2.92 |  | -4.46 | -3.67 | -5.25 | -4.80 | -4.12 |
| Serine | 1.97 | 1.99 | 1.96 | 1.76 | 2.19 |  | -1.91 | -1.48 | -2.35 | -2.16 | -1.67 |
| Threonine | 2.08 | 2.09 | 2.07 | 1.86 | 2.30 |  | -0.54 | -0.24 | -0.85 | -0.79 | -0.29 |
| Tryptophan | 0.34 | 0.35 | 0.34 | 0.30 | 0.38 |  | -0.60 | -0.50 | -0.70 | -0.64 | -0.56 |
| Tyrosine | 1.67 | 1.69 | 1.66 | 1.49 | 1.85 |  | -0.90 | -0.61 | -1.20 | -1.11 | -0.70 |
| Valine | 2.65 | 2.67 | 2.63 | 2.37 | 2.93 |  | -1.19 | -0.75 | -1.64 | -1.52 | -0.88 |
| 1 E = Extensive; M = Intensive maize; beef = beef breed; G = Grazing; I = indoor.2Base = balance of amino acid output – input in the original calculations. |

**References**

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