**Supplementary File – for Online Publication Only**

**Review: Alternative and novel feeds for ruminants - nutritive value, product quality and environmental aspects**

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**Supplementary Table S1** *Full references for the chemical composition of some alternative and common feeds for ruminants in Table 1*

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| Feed | References |
| *Common protein feeds* | |
| Rapeseed expeller | Heuzé V, Tran G, Sauvant D, Lessire M and Lebas F 2017. Rapeseed meal. Retrieved on 27 April 2018, from <http://www.feedipedia.org/node/52> |
| Soybean expeller | Heuzé V, Tran G and Kaushik S 2017. Soybean meal. Retrieved on 27 April 2018, from http://www.feedipedia.org/node/674 |
| *By-products of food industry* | |
| Apple pomace | Wadhwa M, Bakshi MP and Makkar HP 2015. Waste to worth: fruit wastes and by-products as animal feed. CAB Reviews 10, 1-26. |
| Camelinaseed expeller | Heuzé V, Tran G and Lebas F 2017. Camelina (Camelina sativa) seeds and oil meal. Retrieved on 27 April 2018, from <http://www.feedipedia.org/node/4254>  Lawrence RD, Anderson JL and Clapper JA 2016. Evaluation of camelina meal as a feedstuff for growing dairy heifers. Journal of Dairy Science 99, 6215-6228. |
| Cauliflower leaf  Cucumber waste  Grape marc  Tomato fruit waste  Olivesilage (pulp + leaf) | Rinne M, Dragomir C, Kuoppala K, Smith J and Yáñez-Ruiz D 2014. Novel feeds for organic dairy chains. Organic Agriculture 4, 275-284. |
| *Grain legume seeds* |  |
| Faba bean | Heuzé V, Tran G, Delagarde R, Lessire M and Lebas F 2016. Faba bean (Vicia faba). Retrieved on 27 April 2018, from <http://www.feedipedia.org/node/4926> |
| Lupins | Berk A, Bramm A, Böhm H, Aulrich K and Rühl G 2008. The nutritive value of lupins in sole cropping systems and mixed intercropping with spring cereals for grain production. In Proceedings of the 12th International Lupin Conference, Lupins for Health and Wealth, 14-18 September 2008, Fremantle, Western Australia, pp. 66-70.Aulrich K and Rühl G 2008. The nutritive value of lupins in sole cropping systems and mixed intercropping with spring cereals for grain production. In Proceedings of the 12th International Lupin Conference, Lupins for Health and Wealth, 14-18 September 2008, Fremantle, Western Australia, pp. 66-70.  Wasilewko J and Buraczewska L 1999. Chemical composition including content of amino acids, minerals and alkaloids in seeds of three lupin species cultivated in Poland. Journal of Animal and Feed Sciences 81, 1-12. |
| Pea | Heuzé V, Tran G, Giger-Reverdin S, Noblet J, Renaudeau D, Lessire M and Lebas F 2017. Pea seeds. Retrieved on 27 April 2018, from [http://www.feedipedia.org/node/264http://www.feedipedia.org/node/264](http://www.feedipedia.org/node/264) |
| Soybean | Heuzé V, Tran G and Kaushik S 2017. Soybean meal. Retrieved on 27 April 2018, from <http://www.feedipedia.org/node/674> |
| *Grass silage juice* | Franco M, Winquist E, Rinne M. 2018. Grass silage for biorefinery – A meta-analysis of liquid-solid separation. XVIII International Silage Conference, 24-26 July 2018, Bonn, Germany. |
| *Grain legume*  *whole crop stands* | Rinne M, Dragomir C, Kuoppala K, Smith J and Yáñez-Ruiz D 2014. Novel feeds for organic dairy chains. Organic Agriculture 4, 275-284. |
| *Trees or shrubs (leaves unless otherwise stated)* | |
| Cassava  Flemingia | Phesatcha B Wanapat M Phesatcha K Ampapon T and Kang S 2016. Supplementation of Flemingia macrophylla and cassava foliage as a rumen enhancer on fermentation efficiency and estimated methane production in dairy steers. Tropical Animal Health and Production 48, 1449-1454. |
| Leucaena | Phesatcha K and Wanapat M 2017. Tropical legume supplementation influences microbial protein synthesis and rumen ecology. Journal of Animal Physiology and Animal Nutrition 101, 552–562. ‘ |
| Moringa | Makkar HPS and Becker K 1996. Nutritional value and antinutritional components of whole and ethanol extracted Moringa oleifera leaves. Animal Feed Science and Technology 63, 211–228. |
| Pine bark | Kairenius P, Mäntysaari P and Rinne M 2017. The effect of gradual dietary bark meal supplementation on feed intake and milk production of Nordic Red cows fed a grass silage-based diet. Manuscript. |
| Sesbania | Teklea D, Gebrua G, Hagosa H and Belay S 2016. Effect of on farm supplementation of dried Sesbaniasesban (L.) leaf on performance of Abergelle rams. Scientific Journal of Animal Science 5, 322-328. |
| Willow | Smith J, Kuoppala K, Yáñez-Ruiz D, Leach K and Rinne M 2014. Nutritional and fermentation quality of ensiled willow from an integrated feed and bioenergy agroforestry system in UK. . In Proceedings of Maataloustieteen Päivät 2014, 8-9 January 2014, Helsinki, Finland. 9 p. Retrieved on 15 December 2017, from http://www.smts.fi/MTP\_julkaisu\_2014/Posterit/064Smith\_ym\_Nutritional\_and\_fermentation\_quality\_of\_ensiled\_willow.pdf |
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| *Jatropha kernel meal, detoxified* | Heuzé V, Tran G, Edouard N, Renaudeau D, Bastianelli D and Lebas F 2016. Jatropha (*Jatropha* sp.) kernel meal and other jatropha products. Retrieved on 30 November 2017, from [https://www.feedipedia.org/node/620https://www.feedipedia.org/node/620](https://www.feedipedia.org/node/620) |
| *Single-cell protein* |  |
| Bacteria  Fungi  Yeast | Lindberg JE, Lindberg G, Teräs J, Poulsen G, Solberg SØ, Tybirk K, Przedrzymirska J, Sapota GP, Olsen ML, Karlson H, Jóhannsson R, Smárason BÖ, Gylling M, Knudsen MT, Dorca-Preda T, Hermansen JE, Kruklite Z and Berzina I 2016. Nordic Alternative Protein Potentials: Mapping of regional bioeconomy opportunities. Nordic Council of Ministers. Retrieved on 27 April 2018, from <http://www.nordic-ilibrary.org/environment/nordic-alternative-protein-potentials_tn2016-527>, from <http://www.nordic-ilibrary.org/environment/nordic-alternative-protein-potentials_tn2016-527>  Nasseri AT, Rasoul-Amini S, Morowvat MH and Ghasemi Y 2011. Single cell protein: production and process. American Journal of Food Technology 6, 103-116.Ghasemi Y 2011. Single cell protein: production and process. American Journal of Food Technology 6, 103-116. |
| *Microalgae* |  |
| *Chlorella vulgaris*  *Spirulina platensis* | Lamminen M, Halmemies-Beauchet-Filleau A, Kokkonen T, Simpura I, Jaakkola S, Vanhatalo A 2017. Comparison of microalgae and rapeseed meal as supplementary protein in the grass silage based nutrition of dairy cows. Animal Feed Science and Technology 234, 295-311. |
| *Euglena gracilis* | Aemiro A, Watanabe S, Suzuki K, Hanada M, Umetsu K and Nishida T 2016. Effects of Euglena (Euglena gracilis) supplemented to diet (forage: concentrate ratios of 60: 40) on the basic ruminal fermentation and methane emissions in in vitro condition. Animal Feed Science and Technology 212, 129-135. |
| *Scenedesmus obliquus* | Klostermeyer H, Schmandke H, Soeder CJ, Schreiber W, Oehlenschläger J, Scholtyssek S, Kobald M, Sander A, Eilers E, Kries E 2017. Proteins. In Ullmann’s Food and Feed (ed. B Elvers), Wiley-VHC, Weinheim, Germany, vol. 2. pp. 861-914., vol. 2. pp. 861-914. |
| *Schizochytrium sp.* | Madeira MS, Cardoso C, Lopes PA, Coelho D, Afonso C, Bandarra NM and Prates JA 2017. Microalgae as feed ingredients for livestock production and meat quality: a review. Livestock Science 205, 111-121. |
| *Seaweeds* | Makkar HP, Tran G, Heuzé V, Giger-Reverdin S, Lessire M, Lebas F and Ankers P 2016. Seaweeds for livestock diets: a review. Animal Feed Science and Technology 212, 1-17. |
| *Duckweed* | Heuzé V and Tran G 2015. Duckweed. Retrieved on 26 July 2017, from <https://www.feedipedia.org/node/15306> |

**Supplementary Table S2** *Full references for Table 3 reporting the effect of some alternative protein feeds on the milk production of ruminants*

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| No. | Full reference |
| 1 | Halmemies-Beauchet-Filleau A, Kokkonen T, Lampi AM, Toivonen V, Shingfield KJ and Vanhatalo A 2011. Effect of plant oils and camelina expeller on milk fatty acid composition in lactating cows fed diets based on red clover silage. Journal of Dairy Science 94, 4413–4430. |
| 2 | Puhakka L, Jaakkola S, Simpura I, Kokkonen T and Vanhatalo A 2016. Effects of replacing rapeseed meal with fava bean at 2 concentrate crude protein levels on feed intake, nutrient digestion, and milk production in cows fed grass silage–based diets. Journal of Dairy Science 99, 7993-8006. |
| 3 | Halmemies-Beauchet-Filleau A, Lamminen M, Kokkonen T, Vanhatalo A and Jaakkola S 2016. Rapeseed meal, faba beans and microalga (Spirulina platensis) as protein supplements for dairy cows on grass silage based diets. In Proceedings of 5th EAAP International Symposium on Energy and Protein Metabolism and Nutrition, 12-15 September 2016, Krakow, Poland, pp. 281-283. |
| 4 | Kuoppala K, Jaakkola S, Ahvenjärvi S and Rinne M 2016. Härkäpapu ja sinilupiini lypsylehmien valkuaisrehuna. In Proceedings of Maataloustieteen Päivät 2016, 12-13 January 2016, Helsinki, Finland. Retrieved on 15 December 2017, from p. 27. http://www.smts.fi/sites/smts.fi/files/MAATALOUSTIETEEN\_ABSTRAKTIKIRJA2016.pdf |
| 5 | Ramin M, Höjer A and Hetta M 2017. The effects of legume seeds on the lactation performance of dairy cows fed grass silage-based diets. Agricultural and Food Science 26, 129-137. |
| 6 | Volpelli LA, Comellini M, Masoero F, Moschini M, Lo Fiego DP and Scipioni R 2010. Faba beans (Vicia faba) in dairy cow diet: effect on milk production and quality. Italian Journal of Animal Science 9, e27. |
| 7 | Tufarelli V, Khan RU and Laudadio V 2012. Evaluating the suitability of field beans as a substitute for soybean meal in early‐lactating dairy cow: Production and metabolic responses. Animal Science Journal 83, 136-140. |
| 8 | Partially published in Puhakka L, Jaakkola S, Kokkonen T and Vanhatalo A 2017. Blue lupin as an alternative protein supplement for dairy cows fed grass silage-based diets. In Proceedings of NJF Seminar 495, 19-21 June 2017, Mikkeli, Finland, pp. 80. |
| 9 | Singh CK, Robinson PH and McNiven MA 1995. Evaluation of raw and roasted lupin seeds as protein supplements for lactating cows. Animal Feed Science and Technology 52, 63-76. |
| 10 | Robinson PH and McNiven MA 1993. Nutritive value of raw and roasted sweet white lupins (Lupinus albus) for lactating dairy cows. Animal Feed Science and Technology 43, 275-290. |
| 11 | Froidmont E and Bartiaux-Thill N 2004. Suitability of lupin and pea seeds as a substitute for soybean meal in high-producing dairy cow feed. Animal Research 53, 475-487. |
| 12 | Marley C, Davies D, Fisher B, Fychan R, Sanderson R, Jones R and Abberton M 2008. Effects of incorporating yellow lupins into concentrate diets compared with soya on milk production and milk composition when offered to dairy cows. In Proceedings of the 12th International Lupin Conference—Lupins for health and wealth, 14-18 September 2008, Fremantle, Western Australia, pp. 115-117. |
| 13 | Khalili H, Kuusela E, Suvitie M and Huhtanen P 2002. Effect of protein and energy supplements on milk production in organic farming. Animal Feed Science and Technology 98, 103-119. |
| 14 | Corbett RR, Goonewardene LA and Okine EK 1995. Effects of feeding peas to high-producing dairy cows. Canadian Journal of Animal Science 75, 625-629. |
| 15 | Khorasani GR, Okine EK, Corbett RR, Kennelly JJ 2001. Nutritive value of peas for lactating dairy cattle. Canadian Journal of Animal Science 81, 541–551. |
| 16 | Petit HV, Rioux R and Ouellet DR 1997. Milk production and intake of lactating cows fed raw or extruded peas. Journal of Dairy Science 80, 3377-3385. |
| 17 | Vander Pol M, Hristov AN, Zaman S and Delano N 2007. Peas can replace soybean meal and corn grain in dairy cow diets. Journal of Dairy Science 91, 698-703. |
| 18 | Tufarelli V, Naz S, Khan RU, Mazzei D and Laudadio V 2012. Milk quality, manufacturing properties and blood biochemical profile from dairy cows fed peas (Pisum sativum L.) as dietary protein supplement. Tierzucht 55, 132-139. |
| 19 | Lamminen M, Halmemies-Beauchet-Filleau A, Kokkonen T, Simpura I, Jaakkola S and Vanhatalo A 2017. Comparison of microalgae and rapeseed meal as supplementary protein in the grass silage based nutrition of dairy cows. Animal Feed Science and Technology 234, 295-311. |
| 20 | Lamminen M, Halmemies-Beauchet-Filleau A, Kokkonen T, Jaakkola S and Vanhatalo A 2016. Microalgae as a substitute for soya bean meal in the grass silage based dairy cow diets. In Proceedings of 5th EAAP International Symposium on Energy and Protein Metabolism and Nutrition, 12-15 September 2016, Krakow, Poland, pp. 285-287. |
| 21 | Szumacher‐Strabel M, Cieślak A, Zmora P, Pers‐Kamczyc E, Bielińska S, Stanisz M and Wójtowski J 2011. Camelina sativa cake improved unsaturated fatty acids in ewe's milk. Journal of the Science of Food and Agriculture 91, 2031-2037. |
| 22 | Danków R, Pikul J, Wójtowski J, Cais-Sokolińska D, Teichert J, Bagnicka E, Cieslak A and Szumacher-Strabel M 2015. The effect of supplementation with gold of pleasure (Camelina sativa) cake on the fatty acid profile of ewe milk and yoghurt produced from it. Journal of Animal and Feed Sciences 24, 193-202. |
| 23 | Mierlita D and Vicas S 2015. Dietary effect of silage type and combination with camelina seed on milk fatty acid profile and antioxidant capacity of sheep milk. South African Journal of Animal Science 45, 1-11. |
| 24 | Liponi GB, Casini L, Martini M and Gatta 2007. Faba bean (Vicia faba minor) and pea seeds (Pisum sativum) as protein sources in lactating ewes’ diets. Italian Journal of Animal Science 6 (Suppl.1), 309-311. |
| 25 | Bonanno A, Di Grigoli A, Vitale F, Alabiso M, Giosuè C, Mazza F and Todaro M 2016. Legume grain-based supplements in dairy sheep diet: effects on milk yield, composition and fatty acid profile. Animal Production Science 56, 130-140. |
| 26 | Masucci F, Di Francia A, Romano R, di Serracapriola MM, Lambiase G, Varricchio ML and Proto V 2006. Effect of Lupinus albus as protein supplement on yield, constituents, clotting properties and fatty acid composition in ewes’ milk. Small Ruminant Research 65, 251-259. |
| 27 | Renna M, Cornale P, Lussiana C, Malfatto V, Fortina R, Mimosi A and Battaglini LM 2012. Use of Pisum sativum (L.) as alternative protein resource in diets for dairy sheep: effects on milk yield, gross composition and fatty acid profile. Small Ruminant Research 102, 142-150. |
| 28 | Sampelayo MS, Pérez ML, Extremera FG, Boza JJ and Boza J 1999. Use of Different Dietary Protein Sources for Lactating Goats: Milk Production and Composition as Functions of Protein Degradability and Amino Acid Composition1. Journal of Dairy Science 82, 555-565. |
| 29 | Morales ER, Alcaide EM and Sampelayo MR 2008. Milk production of dairy goats fed diets with different legume seeds: effects of amino acid composition of the rumen undegradable protein fraction. Journal of the Science of Food and Agriculture 88, 2340-2349. |

**Supplementary Table S3** *Full reference for Table 4 reporting the effect of some alternative feeds on the average daily gains of ruminants*

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| --- | --- |
| No. | Full reference |
| 1 | Cappellozza BI, Cooke RF, Bohnert DW, Cherian G and Carroll JA 2012. Effects of camelina meal supplementation on ruminal forage degradability, performance, and physiological responses of beef cattle. Journal of Animal Science 90, 4042-4054. |
| 2 | Lawrence RD, Anderson JL and Clapper JA 2016. Evaluation of camelina meal as a feedstuff for growing dairy heifers. Journal of Dairy Science 99, 6215-6228. |
| 3 | Cieslak A, Stanisz M, Wojtowski J, Pers‐Kamczyc E, Szczechowiak J, El‐Sherbiny M and Szumacher‐Strabel M 2013. Camelina sativa affects the fatty acid contents in M. longissimus muscle of lambs. European Journal of Lipid Science and Technology 115, 1258-1265. |
| 4 | Sami AS, Schuster M and Schwarz FJ 2009. Performance, carcass characteristics and chemical composition of beef affected by lupine seed, rapeseed meal and soybean meal. Journal of Animal Physiology and Animal Nutrition 94, 465-473. |
| 5 | Vicenti A, Toteda F, Di Turi L, Cocca C, Perrucci M, Melodia L and Ragni M 2009. Use of sweet lupin (Lupinus albus L. var. Multitalia) in feeding for Podolian young bulls and influence on productive performances and meat quality traits. Meat Science 82, 247-251. |
| 6 | Huuskonen A, Pesonen M and Honkavaara M 2016. Performance and meat quality of Nordic Red and Aberdeen Angus bulls offered faba bean or field pea based whole crop legume-cereal silages. Agricultural and Food Science 25, 1-12. |
| 7 | Murphy SR, McNiven MA, MacLeod JA and Halliday LJ 1993. Grass and lupin silage in rations for beef steers supplemented with barley or potatoes. Animal Feed Science and Technology 40, 273-283. |
| 8 | Purroy A, Echaide H, Muñoz F, Arana A and Mendizabal JA 1993. The effect of protein level and source of legume seeds on the growth and fattening of lambs. Livestock Production Science 34, 93-100. |
| 9 | Stanford K, Lees BM, McAllister TA, Xu ZJ and Cheng KJ 1996. Comparison of sweet white lupin seed, canola meal and soybean meal as protein supplements for lambs. Canadian Journal of Animal Science 76, 215-219. |
| 10 | Lanza M, Bella M, Priolo A and Fasone V 2003. Peas (Pisum sativum L.) as an alternative protein source in lamb diets: growth performances, and carcass and meat quality. Small Ruminant Research 47, 63-68. |
| 11 | Hart KJ, Sinclair LA, Wilkinson RG and Huntington JA 2011. Effect of whole-crop pea (L.) silages differing in condensed tannin content as a substitute for grass silage and soybean meal on the performance, metabolism, and carcass characteristics of lambs. Journal of Animal Science 89, 3663-3676. |
| 12 | Ktita SR, Chermiti A and Mahouachi M 2010. The use of seaweeds (Ruppia maritima and Chaetomorpha linum) for lamb fattening during drought periods. Small Ruminant Research 91, 116-119. |
| 13 | El-Waziry A, Al-Haidary A, Okab A, Samara E and Abdoun K 2015. Effect of dietary seaweed (Ulva lactuca) supplementation on growth performance of sheep and on in vitro gas production kinetics. Turkish Journal of Veterinary and Animal Sciences 39, 81-86. |
| 14 | Belewu MA, Belewu KY and Lawal IA 2013. Cocktail of fungi blend on *Jatropha curcas* kernel cake: effect on feed intake and blood parameters of goat. American-Eurasian Journal of Agricultural and Environmental Sciences 13, 315-320. |
| 15 | El-Zelaky OA, Khalifa EI, Mohamed AH, Bahera KM and Hussein AM 2011. Productive and reproductive performance of rahmani male lambs fed rations containing jatropha cake. Egyptian Journal of Sheep and Goat Sciences 6, 15-24. |

**Supplementary Table S4** *Full reference for Table 5 reporting the effect of using tropical fodder tree and shrubs supplementation on animal performance*

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| --- | --- |
| No. | Full reference |
| 1 | Wanapat M and Kang S 2013. Enriching the nutritive value of cassava as feed to increase ruminant productivity. Journal of Nutritional Ecology and Food Research 1, 262-269. |
| *2* | Wanapat M, Phesatcha K, Viennasay B, Kang S 2016. Performance of tropical dairy cows fed on cassava top silage in rice straw based diet. In Proceedings of the 17th AAAP Animal Science Congress, 22-25 August 2016, Fukuoka, Japan, pp. 201-206. |
| 3 | Giang N, Truong T, Wanapat M, Phesatcha K and Kang S 2016. Level of Leucaena leucocephala silage feeding on intake, rumen fermentation, and nutrient digestibility in dairy steers. Tropical Animal Health and Production 48, 1057-1064. |
| 4 | Phesatcha K and Wanapat M 2016. Tropical legume supplementation inﬂuences microbial protein synthesis and rumen ecology. Journal of Animal Physiology and Animal Nutrition 101, 552–562. |
| 5 | Phesatcha B, Wanapat M, Phesatcha K, Ampapon T and Kang S 2016. Supplementation of Flemingia macrophylla and cassava foliage as a rumen enhancer on fermentation efficiency and estimated methane production in dairy steers. Tropical Animal Health and Production 48, 1449-1454. |



**Supplementary Figure S1** Proposed sustainable ruminant feeding system for smallholder farmers in the tropics

Reference: Wanapat M, Foiklang S, Ampapon T, Mapato C and Cherdthong T 2017. Feeding strategy on farms to improve livestock productivity and reduce methane production. In Proceedings of the 2nd International Conference on Animal Nutrition and Environment, 1-4 November 2017, Khon Kaen, Thailand, pp. 14-29.