The utilization of the products of green-crop fractionation by pigs and ruminants

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Fibrous green crops can be separated by mechanical methods into two fractions: a high-quality fibrous feedstuff for ruminants and a liquid rich in protein, sugars and minerals for non-ruminants. The yields of crude protein (CP) (nitrogen $\times$ 6·25) which can be obtained from grasses and legume crops are substantially greater than for other methods of crop or animal production (Davys, 1973) (Table 1), and the concentration of protein in grass and legume crops when harvested at an immature stage of growth is greater than that required by the most productive ruminant animals. Results from various experiments (Greenhalgh, Reid & Aitken, 1971; Maguire & Brookes, 1973; A. S. Jones, M. Kay, A. Cadenhead & A. Macdearmid, unpublished results) show that the concentration of CP in the dry matter (DM) of green crops harvested frequently (4–5 cuts/year) is greater than that required by highly productive beef and dairy animals (Agricultural Research Council, 1965).

Developments in the mechanical processing of green crops make possible the extraction of protein from many plant species hitherto not utilized in agricultural systems. Several types of processing equipment have been used for the fractionation of green crops, the most widely used being the pulper and belt-press, the screw-press and sugar-cane rollers. Throughout the history of green-crop fractionation several species of plants have been investigated as possible alternative sources of protein to the twenty to thirty plant species currently considered as major protein-producing crops (see Pirie, 1971).

Table 1. *Yields of edible crude protein (nitrogen* $\times$ *6·25) produced under various farming systems (UK) (after Davys,* 1973)

		Yield (kg/ha per year)
Animals	Upland grazing	50–150
	Intensively reared	100–200
	Dairy herd	250–300
Crops	Wheat grain	550
	Potato (*Solanum tuberosum* L.)	600
	Field bean (*Vicia faba* L.)	840
Leaf protein	Lucerne (*Medicago sativa* L.) or Clover (Trifolium sp.)	1100
	Cocksfoot (*Dactylis glomerata* L.)	1800
	Wheat and Mustard (Brassica sp.)	2000

https://doi.org/10.1079/PNS19760034 Published online by Cambridge University Press

The chemical composition of the products of green-crop fractionation

It is difficult to put precise values on the chemical composition of the extracted juice and pulp as these vary considerably depending mainly on: (a) the type of fractionation equipment used and the intensity of extraction (Raymond & Harris, 1957; Knuckles, Bickoff & Kohler, 1972); (b) the crop species (Raymond & Harris, 1957; Connell, 1975); (c) the previous history of the crop with respect to date, stage of growth, prevailing weather conditions at harvest and fertilizer treatment (Allison & Vartha, 1973; Jones, Houseman & Collier, 1975; A. S. Jones, M. Kay, A. Cadenhead & A. Macdearmid, unpublished results); and (d) the extent of any additional processing of the juice and pulp.

Results published by Hollo & Koch (1971), Kohler, Bickoff & De Fremery (1973), Maguire & Brookes (1973), Connell (1975) and Jones *et al.* (1975) give an indication of the composition of the products of fractionation and the extractability of some of the main constituents from ryegrass (Lolium sp.) and lucerne (*Medicago sativa* L.). Values for the major chemical constituents in grass juice, in grass protein coagulum, and in brown juice (the liquid remaining after precipitation of the protein) extracted by a pulper and belt-press are given in Table 2.

Table 2. *Analysis of whole juice, coagulum and brown liquor of grass (after Cheeseman,* 1974)

	Fresh grass juice	Grass protein coagulum	Grass brown liquor
Dry matter (DM) (g/kg)	96	340	54
Composition (g/kg DM)			
Crude protein*	374	594	150
True protein†	275	588	13
Ash	159	57	242
Fat	21	110	1
Soluble carbohydrates	308	57	380
Fibre	6	28	nd

nd, not determined.

*Nitrogen × 6·25.
†Precipitate with trichloroacetic acid (50 g/l).

The differential extraction rates of water, DM and CP from the whole crop processed by the screw-press result in a pulp residue containing about 100 g/kg more DM, and about 10 to 50 g/kg less CP per kg fresh material than the whole crop.

The pulp residue can be utilized by ruminants in the fresh, dried or ensiled form. The extracted juice can be utilized for non-ruminant feeding in the liquid form, or as dried whole juice or as the liquid coalgulated juice (wet curd). Preparations of the dried whole juice or the dried protein-rich coagulum (leaf-protein concentrate, LPC) have been made for use in diets for poultry and man. The amino acid

https://doi.org/10.1079/PNS19760034 Published online by Cambridge University Press

composition of the proteins extracted from grass and lucerne is such that it has been suggested by several workers (Akeson & Stahmann, 1965; Gerloff, Lima & Stahmann, 1965; Stahmann, 1968; Oelshlegel, Schroeder & Stahmann, 1969; Byers, 1971) that the protein could potentially be equal or superior to other protein sources. Gerloff *et al.* (1965) reported that methionine was the limiting amino acid in LPC prepared from several species of crops and that the other essential amino acids were present in amounts usually associated with a high-quality protein.

Juice from fresh green crops is very labile and its composition changes rapidly unless action is taken to prevent enzymic proteolysis and microbiological degradation of the protein and carbohydrates. The changes in the ratio, true protein (TP):CP, and in amino acid composition with respect to time reported by Cheeseman (1974) and Barber, Braude, Florence, Mitchell & Newport (1973) show the rapidity of the loss of nutrients in fresh juice. The TP:CP ratio in fresh juice also declines as the growing season advances (A. S. Jones, M. Kay, A. Cadenhead & A. Macdearmid, unpublished results), the ratios being 0·7:1 and 0·45:1, respectively, for juice extracted from first-cut (28 May) and fifth-cut grass (1 October).

Leaf-protein concentrate (*LPC*)

Several of the earlier trials (Carpenter, 1951; Carpenter, Duckworth & Ellinger, 1952; Cowlishaw, Eyles, Raymond & Tilley, 1954) with LPC suggested a low nutritive value which now appears to have been due to the improper processing of the extracted leaf protein. Duckworth & Woodham (1961) and Henry & Ford (1965) showed the importance of method of drying on the nutritive value of LPC. In the work of Duckworth & Woodham (1961) oven-drying at 100° resulted in a markedly reduced gross protein value (0·390), compared with a value of 0·870 obtained by laboratory-scale freeze-drying. The effect of drying temperature on the nutritive value of LPC obtained from ryegrass leaves was investigated, the conclusion being that damage occurred only when the temperature rose above 82°. Henry & Ford (1965) showed that for LPC prepared from wheat leaves dried by acetone extraction, biological value (BV) and true digestibility (TD) were 0·765 and 0·839, whereas oven-drying (100°) resulted in a reduction of BV to 0·688 and of TD to 0·608. Duckworth & Woodham (1961) also showed that samples of LPC prepared by a process involving acetone extraction were all of high nutritive value and approximately equivalent to soya-bean meal as a supplementary protein source in chick diets.

Henry & Ford (1965) found that in more than half the samples of LPC prepared from fourteen different plant species, the BV was greater than 0·70, which compared well with other vegetable proteins (Henry & Toothill, 1962).

Using an enzymic digestibility procedure (Akeson & Stahmann, 1964), Akeson & Stahmann (1965) showed that the BV of lucerne LPC (0·850) was greater than that of casein (BV 0·760). Hove, Lohrey, Urs & Allison (1974) showed in rat growth trials that lucerne LPC at dietary inclusions of 320 and 480 g/kg promoted poorer weight gains than casein, while at an inclusion rate of 160 g/kg, weight gains for lucerne LPC and casein were similar. Lucerne contains growth-depressant factors, possibly saponins (Birk, 1969), and it has been reported (Ferrando & Spais, 1966; Subba Rau, Mahadeviah & Singh, 1969) that spray-dried, whole lucerne juice is nutritionally inferior to separated lucerne protein, as judged by weight gain and protein efficiency ratio (g body-weight gain/g protein intake).

Two of the earlier experiments with LPC involved assessing its nutritive value with pigs. Barber, Braude & Mitchell (1958) showed that the wet curd (500–600 g moisture/kg, and 100–110 g nitrogen/kg DM) obtained from a mixture of grasses was equal in terms of body-weight gain and food conversion ratio (FCR) (g food DM intake/g live-weight gain) to white fish meal (WFM) for pigs growing between 23 and 55 kg live weight, when given as a protein supplement in practical diets and in diets below normal in their content of supplementary protein. A further trial carried out by Duckworth, Hepburn & Woodham (1961) substantiated these findings. These workers used a commercially dried preparation of wheat-leaf LPC and compared it with WFM in diets composed of barley and millers offals with various levels of total and supplementary protein. The growth rates and FCR of pigs reared from 16 to 45 kg were similar when either 69 g LPC or 80 g WFM were included/kg diet. The diets were formulated to provide similar amounts of total and supplementary protein.

Whole green-crop juice

In more recent work the liquid extract from grass has been evaluated in N-balance trials with pigs (A. S. Jones, M. Kay, A. Cadenhead & A. Macdearmid, unpublished results). In one trial which involved pigs of 30 kg live weight, N retention was significantly improved from 10·7 to 16·9 g/d by the addition of fresh grass juice in the proportion 3·25:1 to a basal diet of barley with 50 g WFM/kg. The value for the diet including grass juice represents near-optimal values for N retention (Thorbek, 1975) for pigs of 30 kg live weight. In a second trial, with 70 kg pigs, equivalent N retention values were obtained for fresh grass juice (22·0 g/d) and WFM (21·5 g/d) when these were given as the sole supplementary sources of protein. In so far that the juice also supplied considerable quantities of energy, the effects of increased level of feeding and protein quality were confounded.

Subsequent work with the whole extracted juice as a component of pig diets has confirmed the results of these experiments, in that the extracted juice has a high nutritive value. Barber, Braude, Florence & Mitchell (1974) showed that the replacement on a TP basis of 35 g WFM/kg contained in control diet, by lucerne or grass juice did not affect the performance of pigs growing between 20 and 60 kg live weight. Maguire (1974) demonstrated the value of grass juice preserved with hydrochloric acid and metabisulphite. Pigs were reared from 32 to 82 kg either on a conventional barley–soya-bean-meal diet (144 g CP/kg) or on a diet in which grass juice obtained from RvP Italian ryegrass (*Lolium italicum* R.Br) provided 220 g/kg total organic matter (OM) intake, 400 g/kg total CP intake, and half the lysine intake. Both diets were fed on a scale providing the same total OM, and daily live-weight gains and FCR were similar for the two treatments.

Using freshly-extracted juice without preservation or further processing, Houseman, Jones, Innes & Collier (1975) showed that the performance and carcass quality of pigs reared from 50 to 105 kg was similar when given diets constituted from either barley–fish meal (145 g CP/kg) or from barley–grass juice (1:3, w/w).

Fresh fibrous residue

In 1957 Raymond & Harris (1957) reported work in which the apparent digestibilities of pulp residues obtained from different crops and by different types of processing were determined. Roller-pressing was compared with screw-pressing, and different levels of juice extraction were also compared. Over all, the average digestibilities of the DM and OM in the pulp residues were 64 and 56 g/kg less than in the fresh crop and the apparent digestibility of N was 83 g/kg lower than in the fresh crop. Screw-pressing reduced the apparent digestibility of DM, OM and N more than roller-pressing, and repeated roller-pressing progressively reduced the digestibility of DM, OM and N. With more moderate juice extraction rates, Houseman, Jones, Innes & Collier (1975) found smaller reductions in the digestibility of DM and OM after pressing: the coefficients for DM and OM obtained after screw-pressing perennial ryegrass (*Lolium perenne* L.) were 0·710 and 0·718 respectively, compared with 0·729 and 0·738 for the fresh whole crop. Similar findings, based on determinations of digestible OM in DM in vitro, in RvP Italian ryegrass have been reported by Maguire & Brookes (1973) and by Greenhalgh & Reid (1975) for the digestibility of DM in sheep, of pulp obtained by twice screw-pressing ryegrass. It would seem that in the process of pulping grass or lucerne a large proportion of the more highly digestible components are removed, leaving a residue with a higher proportion of cell-wall material (see Maguire & Brookes, 1973) and consequently a lower digestibility.

In a growth trial with thirty-six Aberdeen Angus×Friesian heifers which were zero-grazed on fresh grass or pulp *ad lib.*, Houseman *et al.* (1975) reported that the live-weight gains of the cattle offered the pulp were significantly greater than those of cattle offered whole grass (Table 3), but the daily DM intakes of the cattle offered the pulp were significantly lower than those given whole grass.

Table 3. *Performance of cattle given fresh pulp, obtained by screw-pressing grass, or fresh grass (from Houseman, Jones, Innes & Collier* (1975))

	Fresh pulp	Fresh grass
Live-weight gain (kg/d)	0·84	0·73
Fresh matter intake (kg/d)	23·8	40·9
Dry matter (DM) intake (kg/d)	6·26	6·78
Food conversion ratio*	7·45	9·28

*Food DM intake (kg)/kg live-weight gain.

The effect of mechanical processing on the acceptability and digestibility of grass has been investigated by Greenhalgh & Reid (1975). Reconstitution of grass

https://doi.org/10.1079/PNS19760034 Published online by Cambridge University Press

juice and the pulp residue resulted in significantly greater DM intakes in sheep than for chopped whole grass, or the pulp residue. In one trial, in which freshly prepared material was used, the DM intakes were 1730, 1400 and 1380 g/d respectively. The authors suggested the results had shown that the 'potentially detrimental effects of removing soluble nutrients from grass had been counter-balanced by the beneficial effects of comminution'.

Ensiled pulp residue

The pulp residue obtained from grass or lucerne has been reported to ensile easily with relatively small effluent losses (Oelshlegel *et al.* 1969; Jones, McLeod, Macdearmid & Houseman, 1974) although some workers (Raymond & Harris, 1957; Vartha, Allison & Fletcher, 1973) have reported difficulties in the ensiling process due to the low sugar content of the pulp.

The intake and digestibility of DM of ensiled grass pulp by lambs has been shown to be very similar to dried whole grass cut at the same stage of growth (Jones *et al.* 1974), the respective values for the digestibility of DM for the ensiled pulp and dried grass being 0·749 and 0·744. Vartha *et al.* (1973) evaluated lucerne pulp ensiled with molasses and sulphuric acid in polythene bags. They reported an apparent digestibility of OM of 0·649, and a voluntary intake of 98 g DM/kg body-weight$^{0.75}$ in sheep, the intake value they noted to be particularly high compared with that obtained with whole-lucerne silage.

Dried pulp residue

Relatively little work has been carried out with the dried pulp residues, in which nutritive value has been assessed. Raymond & Harris (1957) compared the digestibility of a dried pulp residue, obtained by screw-pressing a grass–clover mixture once, with the dried whole crop in sheep. The digestibility of DM in the dried pulp residue was 0·556 whereas in the whole crop it was 0·643. Determinations in vitro of digestible OM in the DM of dried, wafered whole-crop lucerne and the dried wafered pulp residue were made by Connell & Cramp (1975). The values reported show reductions in digestibility due to processing, being 0·580 and 0·560 for early and late harvested whole-crop lucerne, and 0·550 and 0·510 for early and late harvested lucerne pulp.

These authors also reported that, for dairy cows given wafers made from whole-crop lucerne and lucerne pulp, there were no significant differences between treatments in DM intake, milk quality and live-weight change during part of their lactation, but that milk yield from cows given early-harvested whole-crop lucerne wafers was significantly greater than from cows given the wafers made from late-harvested lucerne pulp.

Conclusions

Mechanical fractionation of green crops provides a means of extracting larger quantities of protein for utilization by non-ruminants, leaving a pulp suitable for ruminant livestock. The yields of primary nutrients such as protein and the essential amino acids extracted from green crops are of the order of two to four times those obtained from other crops grown in the UK, and it has been calculated (Houseman *et al.* 1975) that the carcass output of an animal production system based on green-crop fractionation is about twice that of intensively reared cattle.

In the fractionation of green crops, large quantities of highly digestible nutrients are removed, leaving residues containing relatively larger amounts of cell-wall material. It would be expected, on the basis of chemical analyses, that the residual pulp would have a lower nutritive value than the whole crop. In several experiments, however, it has been demonstrated that pulp residues obtained by moderate juice extraction (approximately 200 g/kg whole-crop DM extracted in the juice) have similar nutritive values to the whole crop, in terms of digestibility of DM and OM, and conversion of DM to live-weight gain, suggesting that there may be modifications in the structural components of the crop due to processing, leading to improved utilization by ruminants. With more intensive juice extraction, results have been published which indicate that the pulp residues may be nutritionally inferior to the whole crop in terms of acceptability and digestibility.

Green crop juice can be utilized by non-ruminant livestock in the liquid form, either freshly extracted or preserved with chemicals, or it can be further processed into a protein-rich coagulum, by removal of a large proportion of the soluble carbohydrates and minerals, and in the instance of leguminous crop juice, of the growth-depressant factors. The dried, protein-rich coagulum, known as LPC, has been shown to be similar in nutritive value to the more conventional protein sources such as soya-bean meal, provided that moderate drying conditions (<82°) are maintained. Drying temperatures above 82° for long periods have been shown to depress the BV and TD of the extracted protein.

Experiments with growing pigs have shown that fresh green-crop juice can promote N retentions, live-weight gains and FCR similar to those obtained from conventional protein sources, and preservation of juice by steaming and the addition of acid and metabisulphite appears to maintain its nutritional value for several days.

From a review of the literature, it is clear that further experimentation is necessary to identify the optimal conditions of mechanical processing, in terms of crop species, stage of crop maturity, intensity of juice extraction and further processing of the juice to obtain maximum utilization of the liquid extract by non-ruminants, and of the pulp residue by ruminant livestock.

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https://doi.org/10.1079/PNS19760034 Published online by Cambridge University Press

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Printed in Great Britain