Some effects of processing on the nutritive value of feedstuffs for growing pigs

By T. L. J. LAWRENCE, *Department of Animal Husbandry, University of Liverpool, Veterinary Field Station, Chester High Road, Wirral, Merseyside L64 7TE*

This paper describes some of those processing techniques which are commonly used at present and those which may find increasing favour in the future. A broad division is that of (a) chemical processing and (b) physical processing.

Chemical processing

1. *Water treatment.* This includes both soaking in water before, and adding water at, feeding. The general thesis is that soaking improves dietary nutritive value by its action on the cereal fraction, causing damaged starch to be converted to dextrins and reducing sugars, either by natural cereal enzyme action or by enzymes produced by the growth of micro-organisms (Willingham, Jensen & McGinnis, 1959; Thomas, Jensen, Leong & McGinnis, 1960; Willingham, McGinnis, Nelson & Jensen, 1960; Burnett, 1962). Such improvements in the nutritive value of barley have given increased growth responses in the chick (Fry, Allred, Jensen & McGinnis, 1957; Willingham *et al.* 1960; Burnett, 1962) but have elicited little or no response in the pig (Woodman, 1925; Barber, Braude & Mitchell, 1962; Gill, 1965; King, 1969; Aumaitre, Henry, Mercier, Ivorec-Szylit & Thivend, 1972; Lawrence, 1973a). There is evidence that adding water at feeding may improve the response of pigs compared with giving the diet dry. Thus Braude (1972), in reviewing the results of forty-four published papers, found that wet feeding had improved growth and food conversion efficiency (FCE) (g body-weight gain/g food intake) in twenty-nine and twenty-five instances, respectively, although approximately one-third of the experiments showed no difference. In view of the fact that in many (e.g. Kornegay & Vander Noot, 1965, 1968; Lawrence, 1967*a*), though not all (e.g. Weissbach & Laube, 1963) experiments no difference in apparent digestibility has been found, it is possible that improvements in FCE from wet feeding may be more apparent than real and due to a smaller wastage of food. The ratio, water:dry food voluntary intake in the pig may be approximately 2·5:1 (Braude, Mitchell, Cray, Franke & Sedgwick, 1959) and if wet feeding is practised then any ratio of water:dry food intake between 1·5:1 and 4:1 would appear to be unlikely to affect performance significantly (Barber, Braude & Mitchell, 1963; Bowland, 1965; Braude & Rowell, 1967; Lawrence, 1967*a*). Higher ratios (and this may be important in the young pig after weaning) may depress growth, but not necessarily FCE, by causing a decreased

https://doi.org/10.1079/PNS19760037 Published online by Cambridge University Press

food intake (Rérat & Fevrier, 1965; Kornegay & Vander Noot, 1965, 1968). Ratios less than 1·5:1 may affect nutrient utilization (Cunningham & Friend, 1966) and although at narrow (2·5:1) ratios low water temperature may have little deleterious effect (Forbes & Walker, 1968), that may not be so if the liquid intake is high (Holmes, 1971).

2. *Enzyme treatment.* Adding α-amylase (*EC* 3.2.1.1) to cereals (particularly some varieties of barley) can improve their nutritive value for the chick (Jensen, Fry, Allred & McGinnis, 1957; Willingham *et al.* 1959; Burnett, 1962; Herstad & McNab, 1975) but with the pig would appear to have no beneficial effect (Burnett & Neil, 1964; Gill, 1965).

3. *Metal salt treatment.* Whole, unextracted cottonseeds and raw soya beans are relatively unpalatable, are poorly utilized and cause growth depression. In cottonseeds gossypol is probably most responsible, and whilst steam cooking and expeller (but not solvent) extraction lessen the effects of this toxin, they damage the proteins present. Soaking of the whole or dehulled seeds in solutions of calcium or iron (particularly the sulphate) salts, followed by drying before feeding, is a promising way of overcoming these problems (Stevenson, Cabell & Kincaid, 1965; Clawson, Maner, Gomez, Flores & Buitrago, 1975; Clawson, Maner, Gomez, Mejia, Flores & Buitrago, 1975). In raw soya beans the deleterious effects of the trypsin inhibitor, soyin or urease (*EC* 3.5.1.5), may to a large extent be overcome by cooking the beans in solutions of, or adding to the dry diet, copper sulphate (Young, Brown, Ashton & Smith, 1970; Young & Smith, 1973).

4. *Organic acid treatment.* Damp grain stored aerobically will heat. This will lead to an increase in fungal growth and may cause a decrease in nutritive value or induce toxicity (Matre, Nordrum, Thorjørnsrud & Homb, 1972; Jones, Mowat, Elliot & Moran, 1974). Without having to resort to anaerobic storage, treating grain with organic acids, of which possibly propionic is the best (Rao, Knake, Deyoe & Allee, 1974), will overcome these problems. The acids have been shown to be efficiently absorbed from the gut (Bowland, 1970; Lawrence, 1973*b*), to give a better control over fungal growth than anaerobic storage (Jones, Donefer & Elliot, 1970; Livingstone, Denerley, Stewart & Elsley, 1971), to inhibit degradative changes leading to the production of acetic and lactic acids and increased concentrations of ammonia and soluble nitrogen (Dumay, Delort-Laval & Zelter, 1972; Darley & Vetter, 1974*a*,*b*,*c*), and possibly to improve the protein quality of the grain by comparison with dried or ensiled grain (Fevrier, Bourdon & Chambolle, 1972; Gaye, 1972). On the debit side, tocopherol levels may quickly decrease (Madsen, Mortensen, Larsen, Laursen, Keller-Neilsen, Welling & Jensen, 1973; Allen, Parr, Bradley, Swannock, Barton & Tyler, 1974; Lawrence, 1975*a*), although it is doubtful if the response of pigs will be affected in consequence (Madsen *et al.* 1973; Lawrence, 1975*a*). Free fatty acid contents may also be higher (Young, Lun & Forshaw, 1972) though this may not depress voluntary intake (Perez-Aleman, Dempster, English & Topps, 1971; English, Topps & Dempster, 1973; Lynch, Hall, Hill, Hatfield & Jensen, 1975) until some 8 months after harvesting (Lawrence, 1975*a*). In many experiments where physical forms of

https://doi.org/10.1079/PNS19760037 Published online by Cambridge University Press

the cereal have been identical better growth and FCE responses have been obtained than with either anaerobically stored (Cole, Dean & Luscombe, 1970; Young, Brown & Sharp, 1970; Livingstone *et al.* 1971) or dried (Lawrence, 1971*a*) grain; the results of Holmes, Bayley & Horney (1973) suggest that acid-treated grain is better utilized because of a partial predigestion of starch molecules and because of an easier penetration of the damp grains by digestive enzymes.

Future uses of organic acids may be in storing undried field beans (*Vicia faba* L.) (Whittemore & Taylor (1973) found better N digestibility compared with dried beans), in accelerating enzyme hydrolysis in the making of fish silage (Tatterson & Windsor, 1974), which can be utilized efficiently by even the very young pig (Seve, Aumaitre & Tord, 1975) and in improving the nutritive value of whole rapeseeds (although conflicting results have so far been produced) (Bowland, 1972; Bowland & Newell, 1974).

Physical processing

1. *Dehulling.* The potentially valuable components of many feedstuffs are relatively unavailable because of the fibrous husk or hull which surrounds them. For example, when the hull is removed from barley (Henry & Bourdon, 1975), whole rapeseeds (Brassica sp.) (Leslie, Summers & Jones, 1973; Seth & Clandinin, 1973; Bayley & Hill, 1975) and horse beans (*Vicia faba.* Var. *equina* Pers.) (Henry & Bourdon, 1973) the nutritive value is markedly improved.

2. *Grinding and rolling of dried and undried cereals.* In cereals, though not necessarily in other feedstuffs (e.g. soya beans (Olsen, 1972)), particle sizes resulting from different rolling and grinding procedures would appear to be able to exert a profound effect on responses by pigs. Whole or very coarsely ground dried barley, oats and maize are eaten reluctantly (Crampton & Bell, 1946; Clawson, 1962; Haugse, Dinusson, Erickson & Bolin, 1966; Maxwell, Reimann, Hoekstra, Kowalczyk, Benevenga & Grummer, 1970). Those whole sorghum (*Sorghum vulgare* Pers.) (Baker & Reinmiller, 1939; Aubel, 1954), maize (Young, 1970), barley (Gill, 1965; Haugse *et al.* 1966; Lawrence, 1970) and wheat (Ivan, Giles, Alimon & Farrell, 1974) grains which are consumed are poorly utilized as are those sorghum (Lawrence, 1967*b*), maize (Clawson, 1962; Lawrence, 1967*b*; Moal & Castaing, 1973) and barley (Lawrence, 1967*b*, 1970; Delort-Laval, 1972) grains which have been very coarsely ground. In terms of smaller barley particle sizes it would appear that particles from screen sizes up to 5·25 mm diameter are unlikely to impair utilization significantly (Lawrence, 1970; Simonsson & Bjorklund, 1970). The use of screen size in this context may, however, have limitations and in terms of 'modulus of fineness of grinding' (Hebblethwaite, 1958; Haigh & Eden, 1973), a tentative conclusion is that any value up to approximately 2·2 will be unlikely to affect utilization. Compared with this, efficient cold rolling is capable of eliciting similar responses (Lawrence, 1970) and may be the technique of choice with wheat because of its high glutelin content (Braude, Townsend, Harrington & Rowell, 1961; Lawrence, 1967*a* and Ivan *et al.* 1974). Oats, with a high crude fibre content, may best be prepared by fine grinding (Woodman, Evans, Menzies &

Kitchen, 1932; Crampton & Bell, 1946; Calder, Davidson, Duckworth, Hepburn, Lucas, Šokarovski & Walker, 1959).

Damp grain is usually difficult to grind. Alternatives are platemilling or rolling, and experiments conducted on the relative efficiencies of these processes applied to barley have given very variable responses (Forbes, Holme & Robinson, 1964; Cole *et al.* 1970; Livingstone & Livingston, 1970; Livingstone *et al.* 1971; Perez-Aleman *et al.* 1971; English *et al.* 1973; Forbes, 1973; Madsen *et al.* 1973; Cole, Brooks, English, Livingstone & Luscombe, 1975). A tentative conclusion from these experiments and work at this centre (Lawrence, 1971*a*) is that within any storage method, efficient rolling is likely to give similar responses to dried ground or rolled barley at moisture levels up to approximately 220 g/kg.

3. *'Dry' heat treatments.* Heat is applied to many feedstuffs for the purposes of drying, reducing enzyme inhibitors, and improving the palatability and nutritive value of cereals by disrupting the protein and starch matrices to render the carbohydrate fraction more available to the animal. Recent reviews of effects in vitro of different heat processes have been those of Hale (1971, 1973), Mercier (1971), Croka & Wagner (1975) and Prasad, Morrill, Melton, Dayton, Arnett & Pfost (1975). Because of wet harvesting conditions cereals often have to be dried and the relatively scarce evidence available on the effects of drying on nutritive value is conflicting. For example, Moal & Castaing (1974) found no effect on the response of pigs from drying maize between 90 and 150° but Costa, Baker, Harmon, Norton & Jensen (1973) and Costa, Jensen & Owens (1973) found a quadratic effect on N retention and growth for pigs of 55 kg, but not for those of 11 kg live-weight. With barley, Delort-Laval (1972) found that high drying temperatures depressed N retention, corresponding to a lower content of total and available lysine. Jones (1974) cites Rowett Research Institute work in which a temperature of 90° as against 55°, 67° and 80° significantly depressed growth, FCE and N digestibility but had no effect on lysine availability.

Heating soya beans (Combs, Conness, Berry & Wallace, 1967) and field beans (Wilson, McNab & Bentley, 1972) has successfully destroyed enzyme inhibitors. In the soya bean, recent evidence suggests that a low roasting temperature of 115° should be aimed at (Seerley, Emberson, McCampbell, Burdick & Grimes, 1974), but that the growth response to temperatures between 110 and 160° is quadratic with the greatest response obtained between 130 and 150° (Olsen, 1972; Olsen, Young, Ashton & Smith, 1975). Soya beans subjected to infrared heat have satisfactory contents of available lysine and urease but give a relatively poor response from pigs (Faber & Zimmerman, 1973). In contrast, micronizing (involving the subjection of foodstuffs to infrared heat) has satisfactorily reduced the trypsin inhibitor content of field beans (McNab & Wilson, 1974) and markedly improved carbohydrate availability in field beans for the chick and in maize (in particular) and barley (Lawrence, 1973*a,c*; Fernandes, Hutton & Smith, 1975), but not in wheat (Lawrence, 1973*a,c*; 1975*b*), for the pig.

4. *'Wet' heat treatments (with and without pressure).* The flaking of cereals is probably the most widely used of the 'wet' heating processes. Early work with

maize (Woodman, 1925; Woodman & Evans, 1932) suggested a large improvement in digestibility from this process but subsequent work has failed to confirm this (Sheehy & Senior, 1939; Burnett & Neil, 1964; Lawrence, 1968, 1972; Borgida, 1975). With wheat and barley very small responses or none have been obtained (Aumaitre *et al.* 1972; Lawrence, 1972). Applying a flaking process to potatoes, however, appears to hold promise of improving nutritive value (Whittemore & Taylor, 1973; Whittemore, Taylor & Elsley, 1973; Whittemore, Taylor & Crooks, 1974; Hillyer & Whittemore, 1975; Whittemore, Moffat & Taylor, 1975), partially by improving N utilization (Whittemore, Taylor, Moffat & Scott, 1975).

Pressure can be applied in pelleting with or without 'wet' heat. The extensive reviews of Vanschoubroek, Coucke & van Spaendonck (1971) and Braude (1972) point overwhelmingly to an improvement in nutritive value and response in pigs from various pelleting procedures applied to a wide range of diets. Depending on the nature of the feeding-stuff(s) such improvement may be due to reduced food intakes or less food wastage or both (Baird, 1973), to better digestibility (Olsen & Slinger, 1968; Lawrence, 1971*b*) or to improved amino acid (Yen, Baker, Harmon & Jensen, 1971) and phosphorus (Bayley, Pos & Thomson, 1975) availability. The results of Melcion, Vaissade, Valdebouze & Viroben (1974) do not suggest that the pressure component of the process is more important than the heat component but the results of Lawrence (1971*b*) and Mercier & Guilbot (1974) point to pressure as being the more important of the two.

REFERENCES

Allen, W. M., Parr, W. H., Bradley, R., Swannock, K., Barton, C. R. Q. & Tyler, R. (1974). *Vet. Rec.* **94**, 373.

Aubel, C. E. (1954). *Circ. Kans. agric. Exp. Stn* no. 308.

Aumaitre, A., Henry, Y., Mercier, C., Ivorec-Szylit, O. & Thivend, P. (1972). *Annls Zootech.* **21**, 133.

Baird, D. M. (1973). *J. Anim. Sci.* **36**, 516.

Baker, M. L. & Reinmiller, C. F. (1939). *Bull. Neb. agric. Exp. Stn* no. 323.

Barber, R. S., Braude, R. & Mitchell, K. G. (1962). *Anim. Prod.* **4**, 313.

Barber, R. S., Braude, R. & Mitchell, K. G. (1963). *Anim. Prod.* **5**, 277.

Bayley, H. S. & Hill, D. C. (1975). *Can. J. Anim. Sci.* **55**, 223.

Bayley, H. S., Pos, J. & Thomson, R. G. (1975). *J. Anim. Sci.* **40**, 851.

Borgida, L. P. (1975). *Journées Rech. Porcine France* (1975), p. 99.

Bowland, J. P. (1965). *44th Annual Feeders Day, Department of Animal Science, University of Alberta* (1965), p. 18.

Bowland, J. P. (1970). *49th Annual Feeders Day, Department of Animal Science, University of Alberta* (1970), p. 14.

Bowland, J. P. (1972). *51st Annual Feeders Day, Department of Animal Science, University of Alberta* (1972), p. 1.

Bowland, J. P. & Newell, J. A. (1974). *Can. J. Anim. Sci.* **54**, 455.

Braude, R. (1972). In *Pig Production* [D. J. A. Cole, editor]. London: Butterworth.

Braude, R., Mitchell, K. G., Cray, A. S., Franke, A. & Sedgwick, P. H. (1959). *J. agric. Sci., Camb.* **52**, 223.

Braude, R. & Rowell, J. G. (1967). *J. agric. Sci., Camb.* **68**, 325.

Braude, R., Townsend, J., Harrington, G. & Rowell, J. G. (1961). *J. agric. Sci., Camb.* **57**, 257.

Burnett, G. S. (1962). *Br. Poult. Sci.* **3**, 89.

Burnett, G. S. & Neil, E. L. (1964). *Anim. Prod.* **6**, 237.

Calder, A. F., Davidson, J., Duckworth, J., Hepburn, W. R., Lucas, I. A. M., Šokarovski, J. & Walker, D. M. (1959). *J. Sci. Fd Agric.* **10**, 682.

Clawson, A. J. (1962). *J. Anim. Sci.* **21**, 377.

https://doi.org/10.1079/PNS19760037 Published online by Cambridge University Press

Clawson, A. J., Maner, J. H., Gomez, G., Flores, Z. & Buitrago, J. (1975). *J. Anim. Sci.* **40**, 648.
Clawson, A. J., Maner, J. H., Gomez, G., Mejia, O., Flores, Z. & Buitrago, J. (1975). *J. Anim. Sci.* **40**, 640.
Cole, D. J. A., Brooks, P. H., English, P. R., Livingstone, R. M. & Luscombe, J. R. (1975). *Anim. Prod.* **21**, 295.
Cole, D. J. A., Dean, G. W. & Luscombe, J. R. (1970). *Anim. Prod.* **12**, 1.
Combs, G. E., Conness, R. G., Berry, T. H. & Wallace, H. D. (1967). *J. Anim. Sci.* **26**, 1067.
Costa, P. M. A., Baker, D. H., Harmon, B. G., Norton, H. W. & Jensen, A. H. (1973). *J. Anim. Sci.* **37**, 278.
Costa, P. M. A., Jensen, A. H. & Owens, F. N. (1973). *J. Anim. Sci.* **37**, 278.
Crampton, E. W. & Bell, J. M. (1946). *J. Anim. Sci.* **5**, 200.
Croka, D. C. & Wagner, D. G. (1975). *J. Anim. Sci.* **40**, 931.
Cunningham, H. M. & Friend, D. W. (1966). *J. Anim. Sci.* **25**, 663.
Darley, M. R. & Vetter, R. L. (1974*a*). *J. Anim. Sci.* **38**, 417.
Darley, M. R. & Vetter, R. L. (1974*b*). *J. Anim. Sci.* **38**, 424.
Darley, M. R. & Vetter, R. L. (1974*c*). *J. Anim. Sci.* **38**, 430.
Delort-Laval, J. (1972). *Journées Rech. Porcine France* (1972), p. 115.
Dumay, C., Delort-Laval, J. & Zelter, S. Z. (1972). *Journées Rech. Porcine France* (1972), p. 127.
English, P. R., Topps, J. H. & Dempster, D. G. (1973). *Anim. Prod.* **17**, 75.
Faber, J. L. & Zimmerman, J. (1973). *J. Anim. Sci.* **36**, 902.
Fernandes, T. H., Hutton, K. & Smith, W. C. (1975). *Anim. Prod.* **20**, 307.
Fevrier, C., Bourdon, D. & Chambolle, M. (1972). *Journées Rech. Porcine France* (1972), p. 135.
Forbes, T. J. (1973). *Rec. agric. Res. N. Ire.* **21**, 47.
Forbes, T. J., Holme, D. W. & Robinson, K. L. (1964). *Rec. agric. Res. N. Ire.* **13**, 151.
Forbes, T. J. & Walker, N. (1968). *J. agric. Sci., Camb.* **71**, 145.
Fry, R. E., Allred, J. B., Jensen, L. S. & McGinnis, J. (1957). *Proc. Soc. exp. Biol. Med.* **95**, 249.
Gaye, M. (1972). *Journées Rech. Porcine France* (1972), p. 143.
Gill, D. R. (1965). *Diss. Abstr.* **25**, 6862.
Haigh, P. M. & Eden, A. (1973). *J. agric. Sci., Camb.* **81**, 353.
Hale, W. H. (1971). *Feedstuffs, Minneap.* **43**, 19.
Hale, W. H. (1973). *J. Anim. Sci.* **37**, 1075.
Haugse, C. N., Dinusson, W. E., Erickson, D. O. & Bolin, D. W. (1966). *Rep. N. Dak. agric. Exp. Stn* no. 17.
Hebblethwaite, P. (1958). *J. agric. Engng Res.* **3**, 350.
Henry, Y. & Bourdon, D. (1973). *Journées Rech. Porcine France* (1973), p. 105.
Henry, Y. & Bourdon, D. (1975). *Journées Rech. Porcine France* (1975), p. 71.
Herstad, O. & McNab, J. M. (1975). *Br. Poult. Sci.* **16**, 1.
Hillyer, G. M. & Whittemore, C. T. (1975). *J. Sci. Fd Agric.* **26**, 1215.
Holmes, C. W. (1971). *Anim. Prod.* **13**, 1.
Holmes, J. H. G., Bayley, H. S. & Horney, F. D. (1973). *Br. J. Nutr.* **30**, 401.
Ivan, M., Giles, L. R., Alimon, A. R. & Farrell, D. J. (1974). *Anim. Prod.* **19**, 359.
Jensen, L. S., Fry, R. E., Allred, J. B. & McGinnis, J. (1957). *Poult. Sci.* **36**, 919.
Jones, A. S. (1974). In *Nutritional Developments in the Feeding of Cereals to Pigs*. London: US Feed Grains Council.
Jones, G. M., Donefer, E. & Elliot, J. I. (1970). *Can. J. Anim. Sci.* **50**, 483.
Jones, G. M., Mowat, D. N., Elliot, J. I. & Moran, E. T. (1974). *Can. J. Anim. Sci.* **54**, 499.
King, J. O. L. (1969). *Expl Husb.* no. 18, p. 25.
Kornegay, E. T. & Vander Noot, G. W. (1965). *J. Anim. Sci.* **24**, 892.
Kornegay, E. T. & Vander Noot, G. W. (1968). *J. Anim. Sci.* **27**, 1307.
Lawrence, T. L. J. (1967*a*). *J. agric. Sci., Camb.* **68**, 269.
Lawrence, T. L. J. (1967*b*). *J. agric. Sci., Camb.* **69**, 271.
Lawrence, T. L. J. (1968). *J. agric. Sci., Camb.* **70**, 287.
Lawrence, T. L. J. (1970). *Anim. Prod.* **12**, 139.
Lawrence, T. L. J. (1971*a*). *J. Sci. Fd Agric.* **22**, 407.
Lawrence, T. L. J. (1971*b*). *J. Sci. Fd Agric.* **22**, 403.
Lawrence, T. L. J. (1972). *J. agric. Sci., Camb.* **79**, 155.
Lawrence, T. L. J. (1973*a*). *Anim. Prod.* **16**, 99.
Lawrence, T. L. J. (1973*b*). *Int. Res. Commun. Syst.* (73–3) 45–6–1.

https://doi.org/10.1079/PNS19760037 Published online by Cambridge University Press

Lawrence, T. L. J. (1973*c*). *Anim. Prod.* **16**, 109.
Lawrence, T. L. J. (1975*a*). *Proc. Br. Soc. Anim. Prod.* **4**, 118.
Lawrence, T. L. J. (1975*b*). *Anim. Prod.* **20**, 167.
Leslie, A. J., Summers, J. D. & Jones, J. D. (1973). *Can. J. Anim. Sci.* **53**, 153.
Livingstone, R. M., Denerley, H., Stewart, C. S. & Elsley, F. W. H. (1971). *Anim. Prod.* **13**, 547.
Livingstone, R. M. & Livingston, D. M. S. (1970). *Anim. Prod.* **12**, 561.
Lynch, P. B., Hall, G. E., Hill, L. D., Hatfield, E. E. & Jensen, A. H. (1975). *J. Anim. Sci.* **40**, 1063.
McNab, J. M. & Wilson, B. J. (1974). *J. Sci. Fd Agric.* **25**, 395.
Madsen, A., Mortensen, H. P., Larsen, A. E., Laursen, B., Keller-Neilsen, E., Welling, B. & Jensen, A. H. (1973). *Beretn. Forsøgslab.* no. 407.
Matre, T., Nordrum, E., Thorjørnsrud, B. & Homb, B. T. (1972). *Beretn. Inst. Husdyrernaering og Foringslaere, Norges Landbrukshøgskale* no. 151.
Maxwell, C. V., Reimann, E. M., Hoekstra, W. G., Kowalczyk, T., Benevenga, N. J. & Grummer, R. H. (1970). *J. Anim. Sci.* **30**, 911.
Melcion, J. P., Vaissade, P., Valdebouze, P. & Viroben, G. (1974). *Annls Zootech.* **23**, 149.
Mercier, C. (1971). *Feedstuffs, Minneap.* **43**, 33.
Mercier, C. & Guilbot, A. (1974). *Annls Zootech.* **23**, 241.
Moal, J. & Castaing, J. (1973). *Journées Rech. Porcine France* (1973), p. 75.
Moal, J. & Castaing, J. (1974). *Journées Rech. Porcine France* (1974), p. 193.
Olsen, E. M. (1972). *Diss. Abstr.* **32**, 4695.
Olsen, E. M. & Slinger, S. J. (1968). *Can. J. Anim. Sci.* **48**, 35.
Olsen, E. M., Young, L. G., Ashton, G. C. & Smith, G. C. (1975). *Can. J. Anim. Sci.* **55**, 431.
Perez-Aleman, S., Dempster, D. G., English, P. R. & Topps, J. H. (1971). *Anim. Prod.* **13**, 271.
Prasad, D. A., Morrill, J. L., Melton, S. L., Dayton, A. D., Arnett, D. W. & Pfost, H. B. (1975). *J. Anim. Sci.* **41**, 578.
Rao, C. S., Knake, R. P., Deyoe, C. W. & Allee, G. L. (1974). *Feedstuffs, Minneap.* **46**, 41.
Rérat, A. & Fevrier, C. (1965). *Annls Zootech.* **14**, 39.
Seerley, R. W., Emberson, J. W., McCampbell, H. C., Burdick, D. & Grimes, L. W. (1974). *J. Anim. Sci.* **39**, 1082.
Seth, P. C. C. & Clandinin, D. R. (1973). *Br. Poult. Sci.* **14**, 499.
Seve, B., Aumaitre, A. & Tord, P. (1975). *Annls Zootech.* **24**, 21.
Sheehy, E. J. & Senior, B. J. (1939). *J. Dep. Agric. Repub. Ire.* **36**, 230.
Simonsson, A. & Bjorklund, N. E. (1970). *Proc. Soviet-Swedish Symp., Ultuna, September* 1970.
Stevenson, J. W., Cabell, C. A. & Kincaid, C. M. (1965). *J. Anim. Sci.* **24**, 290.
Thomas, J. M., Jensen, L. S., Leong, K. C. & McGinnis, J. (1960). *Proc. Soc. exp. Biol. Med.* **103**, 198.
Tatterson, I. N. & Windsor, M. L. (1974). *J. Sci. Fd Agric.* **25**, 369.
Vanschoubroek, F., Coucke, L. & van Spaendonck, R. (1971). *Nutr. Abstr. Rev.* **41**, 1.
Weissbach, F. & Laube, W. (1963). *Arch. Tierz.* **9**, 333.
Whittemore, C. T., Moffat, I. W. & Taylor, A. G. (1975). *J. Sci. Fd Agric.* **26**, 1567.
Whittemore, C. T. & Taylor, A. G. (1973). *J. Sci. Fd Agric.* **24**, 1133.
Whittemore, C. T., Taylor, A. G. & Crooks, P. (1974). *J. agric. Sci., Camb.* **83**, 1.
Whittemore, C. T., Taylor, A. G. & Elsley, F. W. H. (1973). *J. Sci. Fd Agric.* **24**, 539.
Whittemore, C. T., Taylor, A. G., Moffat, I. W. & Scott, A. J. (1975). *J. Sci. Fd Agric.* **26**, 225.
Willingham, H. E., Jensen, L. S. & McGinnis, J. (1959). *Poult. Sci.* **38**, 539.
Willingham, H. E., McGinnis, J., Nelson, F. & Jensen, L. S. (1960). *Poult. Sci.* **39**, 1307.
Wilson, B. J., McNab, J. M. & Bentley, H. (1972). *J. Sci. Fd Agric.* **23**, 679.
Woodman, H. E. (1925). *J. agric. Sci., Camb.* **15**, 1.
Woodman, H. E. & Evans, R. E. (1932). *J. agric. Sci., Camb.* **22**, 670.
Woodman, H. E., Evans, R. E., Menzies, A. W. & Kitchen, T. (1932). *J. agric. Sci., Camb.* **22**, 657.
Yen, J. T., Baker, D. H., Harmon, B. G. & Jensen, A. H. (1971). *J. Anim. Sci.* 33, 987.
Young, L. G. (1970). *Can. J. Anim. Sci.* **50**, 705.
Young, L. G., Brown, R. G., Ashton, G. C. & Smith, G. C. (1970). *Can. J. Anim. Sci.* **50**, 717.
Young, L. G., Brown, R. G. & Sharp, B. A. (1970). *Can. J. Anim. Sci.* **50**, 711.
Young, L. G., Lun, A. & Forshaw, R. P. (1972). *J. Anim. Sci.* **35**, 1112.
Young, L. G. & Smith, G. C. (1973). *Can. J. Anim. Sci.* **53**, 587.

Printed in Great Britain