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# Nutritional diversity of agricultural and agro-industrial by-products for ruminant feeding

[*Diversidade nutricional de subprodutos agrícola e agro-industrial para alimentação de ruminantes*]

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## ABSTRACT

Fifty-seven by-products were collected from regions throughout Brazil. Chemical composition, in vitro neutral detergent fiber digestibility (IVNDFD), and total digestible nutrients (TDN) were determined with the objective of grouping by-products with similar nutritional characteristics. The by-products belonging to group one (G1) presented the highest content of neutral detergent fiber exclusive of ash and nitrogenous compounds [aNDFom(n)] and lowest energy content, with 42.5% and 38.8% of IVNDFD and TDN, respectively. A new cluster analysis was carried in order to better characterize G2 by-products, six subgroups (SGs) were established (SG1 to SG6). SG1 by-products had the highest and the lowest values for lignin and TDN, respectively. SG2 by-products had the highest aNDFom(n) value, with TDN and IVNDFD values greater than 600 and 700g/kg, respectively, and crude protein (CP) value below 200g/kg in dry matter (DM). Among all the subgroups, SG3 had the highest TDN (772g/kg) and IVNDFD (934g/kg) values and the lowest lignin (23g/kg in DM) value. The ether extract was what most influenced the hierarchical establishment of residual grouping in SG4. SG5 by-products had the highest concentration of non-fibrous carbohydrate. Different from the other subgroups, SG6 by-products had the highest value of available CP.

Keywords: alternative feed, nutritive value, residues, waste

## RESUMO

*Cinquenta e sete subprodutos foram coletados de diferentes regiões do Brasil. Foram determinados a composição química, a digestibilidade* in vitro *da fibra em detergente neutro (DIVFDN) e os nutrientes digestíveis totais (NDT), com o objetivo de agrupar os subprodutos com características nutricionais semelhantes. Os subprodutos pertencentes a um grupo (G1) apresentaram maior conteúdo de fibra em detergente neutro corrida para cinzas e compostos nitrogenados (FDNcp) e menor teor energético, e tinham 42,5% e 38,8% de DIVFDN e NDT, respectivamente. Uma nova análise de cluster foi realizada no intuito de melhor caracterizar os subprodutos do G2; seis subgrupos (SG) foram estabelecidos (SG1 a SG6). Os subprodutos SG1 tiveram os maiores e os menores valores de lignina e NDT, respectivamente. Os subprodutos SG2 tiveram o maior valor de FDNcp, com valores de NDT e DIVFDN acima de 600 e 700g/kg, respectivamente, e de proteína bruta (PB) abaixo de 200g/kg de matéria seca (MS). Entre todos os subgrupos, SG3 tiveram os maiores valores de NDT (772g/kg) e DIVFDN (934g/kg) e o menor valor de lignina (23g/kg de MS). O extrato etéreo foi o que mais influenciou no estabelecimento hierárquico de agrupamento em SG4. Os subprodutos SG5 tinham maior concentração de carboidratos não fibriosos. Diferentemente dos demais subgrupos, subprodutos SG6 tinham o valor mais elevado de PB disponível.*

*Palavras-chave: alimentos alternativos, valor nutritivo, resíduos, perdas*

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## INTRODUCTION

Brazilian agribusiness data obtained by the Brazilian Confederation of Agricultural and Livestock of the University of São Paulo in 2007 reported a crop record of 131.5 million tons of grain, contributing approximate revenue of US$ 359.9 billion to the gross domestic product (Cieglinski, 2008).

In spite of the optimistic growth of Brazil´s agribusiness and its importance to the Brazilian economy, the quality and diversity of generated agricultural and agro-industrial by-products are a concern because its volume is proportional to the agribusiness growth.

One Brazilian estimate, based on 2002/2003 crop data, indicated a waste of 32 million tons of food between production to final consumer, or, in other words, an approximate loss of 150g/kg of the total feedstuff of grains, fruits, vegetables, and animal products produced *(*CNPq, 2005).

Furthermore, these feedstuffs are not only natural resource losses, when stored in inadequate places they can also lead to serious environmental contamination, mainly of water and soil resources.

Ruminants play a valuable role in sustainable agricultural systems since they are capable of converting renewable natural resources, such as agricultural and agro-industrial by-products, into high quality feed for man (Oltjen and Beckett, 1996).

It is within this context that research on the quality and viability of agricultural and agro-industrial by-products and their use as alternative feed has grown world-wide. However, due to lack of current data, particularly in regard to nutritional value in the alternative feed, the aim of this present study was to estimate the chemical composition, the in vitro neutral detergent fiber digestibility (IVNDFD), the energy value, and the characterization of agricultural and agro-industrial by-products with cluster analysis.

## MATERIALS AND METHODS

This study was carried out in the Animal Science Department of the Center of Agrarian Sciences of the Federal University of Viçosa, Viçosa, MG, Brazil.

Fifty-seven samples of agricultural and agro-industrial by-products were collected from different regions throughout Brazil (African oil meal, Manufactures of soap (palm), Palm meal – *Elaeis guineensis*; Barbados cherry juice residue – *Malpighia glabra*; Brewer residue – *Hordeum vulgare*; Carrot discard human residue, Carrot leaf , Carrot shaving, Carrot thick residue – *Daucus carota*; Cassava flower processing, Cassava foliage, Cassava hull, Cassava hull dirty, Cassava hull thread, Cassava leaf, Cassava shaving, Cassava stalk – *Manihot esculenta*; Castor bran, Castor detoxicated bran – *Ricinus communis*; Citrus pulp – *Citrus sinensis*; Cocoa eed hull, Cocoa meal – *Theobroma cacao*; Coffee hull, Coffee parchment – *Coffea arábica*; Cotton bran, Cotton seed – *Gossypium hirsutum*; Cracked bean – *Phaseolus vulgaris*; Cracker meal – *Triticum vulgare*; Genipap juice residue – *Genipa americana*; Grape wine residue – *Vitis labrusca*; Guava juice residue – *Psidium guajava*; Jack fruit, Jack fruit silage – *Artocarpus heterophyllus*; Mango hull, Mango internal seed, Mango juice residue, Mango outward seed – *Mangifera indica*; Papaya juice residue, Papaya seed, Papaya without seed – *Carica papaya;* Passion fruit – *Passiflora ligulari*, Peach palm – *Bactris gasipae;* Pearl millet – *Pennisetum americanum;* Pineapple crown, Pineapple hull, Pineapple juice residue – *Ananas comosus;* Protein bran – *Zea mays;* Pumpkin seed – *Cucúrbita moschata;* Radish biofuel residue – *Raphanus sativus;* Rice hull – *Oryza sativa;* Soursop juice residue – *Anona muricata;* Soybean hull – *Glycine Max;* Sunflower biofuel residue – *Helianthus annuus;* Tamarind juice residue – *Tamarindus indica;* Uricury bran – *Syagrus coronata;* Wild cabbage residue, Wild cabbage stalk – *Brassica oleracea*).

The agricultural and agro-industrial by-products were oven dried at 55ºC for 48 hours, bulked, sampled, and ground to pass through a 1mm screen for later analysis of the dry matter (DM), crude protein (CP), organic matter (OM), ether extract (EE) and acid detergent fiber (ADF), according to AOAC (Association…, 1990) methods. In the analysis of neutral detergent fiber (NDF) the samples were treated with heat-stable alpha-amylase, without sodium-sulfite, and corrected for ash and nitrogenous compounds [aNDFom(n)] (Mertens, 1992). The correction of NDF and ADF for nitrogenous compounds and the estimation of the contents of insoluble nitrogenous compounds in neutral (NDIN) and acid (ADIN) detergents were made according to Licitra *et al*. (1996). Lignin (LIG) contents were obtained through solubilization of cellulose with sulfuric acid (Van Soest and Robertson, 1985).

The non-fibrous carbohydrate (NFC) contents from the DM of the by-products were calculated according to Hall (2000) as 100 - NDF – CP – EE – ash (g/kg in the DM). The contents of available crude protein (ACP) were claculated as (CP – ADIN x 6.25). TDN at maintenance values were estimated according to equations recommended by NRC (National…, 2001).

Glass test tubes were used for incubation according to procedures described by Schofield *et al*. (1994). The 50mL glass test tubes were previously washed with distilled water and dried in a sterilizer. Approximately 200mg of substrate (residue to be studied) were subsequently placed in the tubes in three replicates. The buffer solution, as described by Menke and Steingass (1988), was prepared and placed in a water bath at 39ºC under continuous flushing with $CO_2$.

Rumen fluid was manually collected before the morning feeding, stored in insulated flasks, which were preheated at 39ºC, and then immediately taken to the laboratory. In the acclimatized room of the laboratory, also at 39ºC, the rumen fluid was filtered through four layers of cheese-cloth (gauzes) and subsequently added (1:2 v/v) to the buffered solution under continuous flushing with $CO_2$.

Three test tubes per residue were prepared with 30mL of the buffered rumen fluid added to the substrate and immediately sealed with rubber corks and aluminum rings to ensure complete maintenance of gases inside.

Following 48 hours of incubation, the test tubes were removed from the acclimatized room and refrigerated at 4ºC to halt the fermentation process. The contents of each test tube were filtered in a Gooch crucible (porosity 0), washed with warm distilled water and acetone. Subsequently 30mL of neutral detergent solution were added to each test tube (Mertens, 2002); the test tubes were sterilized for 60 minutes at 105ºC according to the technique proposed by Pell and Schofield (1993); the contents of each test tube were filtered in a Gooch crucible (porosity 0), washed with warm distilled water and acetone, and dried in a sterilizer at 105ºC for 16 hours.

Cluster analysis was used to assess the divergence in nutritional value of by-products based on the discriminatory variables included (Johnson and Wichern, 1988). Specifically, the average Euclidean distance between standardized variables was used to measure the disimilarity and the minimum variance. PROC UNIVARIATE by SAS (Statistical , 2000) was used for analysis of descriptive statistics and for cluster analyses we used PROC CLUSTER, METHOD=WARD by SAS (Statistical…, 2000).

## RESULTS

The chemical composition, IVNDFD and TDN of fifty-seven by-products is found in Table 1. Based on the discriminatory variables (IVNDFD and TDN) and on the dissimilarity expressed by the average Euclidean distance between variables, a new set of variables establishing hierarchy levels and clustering of the 57 by-products into two distinct groups was created, such that homogeneity was greatest within each group and heterogeneity was greatest across the groups.

Descriptive statistics for IVNDFD and TDN are listed in Table 2, other than the distribution of the 57 agricultural and agro-industrial by-products. There was an efficiency in the clustering obtained with the discriminatory variables (IVNDFD and TDN), even though IVNDFD in G1 group presented as heterogeneous with the highest variation coefficient (45.7%) when all other variables presented variation coeficients below 16.1%.

On average, the by-products belonging to G1 contained 425g/kg DM (SD 194) of IVNDFD and 388g/kg TDN (SD 62) respectively.With 17.5% of all by-products clustered, those belonging to G1 can be better visualized from the behavior of the dissimilarity dendogram established (Figure 1).

Table 1. Chemical composition, *in vitro* neutral detergent fiber digestibility (IVNDFD) and total digestible nutrients (TDN) of by-products

| Residue | DM [a] | OM [b] | CP [b] | NDIN [c] | ADIN [c] | EE [b] | aNDFom(n) [b] | NFC [b] | ADF(n) [b] | LIG [b] | IVNDF [a] | TDN [a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| African oil meal | 924 | 970 | 161 | 949 | 583 | 107 | 523 | 179 | 266 | 112 | 651 | 530 |
| Barbados cherry juice residue | 171 | 971 | 85 | 627 | 26 | 17 | 493 | 376 | 451 | 167 | 607 | 521 |
| Brewer residue | 264 | 959 | 345 | 589 | 559 | 92 | 331 | 192 | 138 | 87 | 669 | 580 |
| Carrot discard human residue | 89 | 913 | 124 | 151 | 106 | 12 | 141 | 636 | 138 | 1 | 953 | 780 |
| Carrot leaf | 226 | 638 | 145 | 762 | 634 | 10 | 75 | 408 | 311 | 91 | 822 | 446 |
| Carrot shaving | 87 | 894 | 112 | 321 | 273 | 27 | 186 | 570 | 181 | 15 | 939 | 715 |
| Carrot thick residue | 85 | 881 | 147 | 827 | 228 | 20 | 137 | 578 | 206 | 26 | 933 | 701 |
| Cassava flower processing | 439 | 988 | 30 | 550 | 146 | 9 | 15 | 935 | 32 | 6 | 982 | 881 |
| Cassava foliage | 219 | 918 | 242 | 598 | 560 | 24 | 404 | 248 | 227 | 96 | 709 | 523 |
| Cassava hull | 256 | 966 | 37 | 588 | 74 | 6 | 158 | 766 | 153 | 55 | 872 | 757 |
| Cassava hull dirty | 250 | 953 | 34 | 647 | 362 | 2 | 208 | 710 | 246 | 126 | 672 | 670 |
| Cassava hull thread | 266 | 919 | 34 | 547 | 277 | 11 | 127 | 747 | 246 | 88 | 734 | 706 |
| Cassava leaf | 219 | 929 | 215 | 669 | 406 | 40 | 303 | 371 | 201 | 110 | 746 | 581 |
| Cassava shaving | 918 | 949 | 29 | 242 | 160 | 12 | 175 | 732 | 202 | 43 | 875 | 744 |
| Cassava stalk | 900 | 963 | 54 | 472 | 213 | 9 | 651 | 248 | 560 | 200 | 321 | 412 |
| Castor bran | 915 | 914 | 397 | 263 | 243 | 25 | 360 | 132 | 294 | 262 | 608 | 453 |
| Castor detoxicated bran | 906 | 924 | 405 | 420 | 38 | 24 | 346 | 149 | 424 | 313 | 579 | 496 |
| Citrus pulp | 859 | 943 | 64 | 587 | 277 | 21 | 206 | 652 | 192 | 27 | 922 | 742 |
| Cocoa eed hull | 893 | 926 | 143 | 551 | 475 | 51 | 370 | 362 | 333 | 185 | 680 | 499 |
| Cocoa meal | 947 | 909 | 159 | 945 | 326 | 166 | 190 | 394 | 230 | 106 | 756 | 637 |
| Coffee hull | 905 | 924 | 117 | 366 | 229 | 10 | 571 | 225 | 458 | 175 | 619 | 425 |
| Coffee parchment | 917 | 988 | 37 | 326 | 247 | 7 | 905 | 39 | 728 | 227 | 163 | 311 |
| Cotton bran | 905 | 955 | 265 | 171 | 102 | 20 | 516 | 154 | 406 | 96 | 709 | 564 |
| Cotton seed | 930 | 958 | 205 | 74 | 62 | 182 | 416 | 154 | 344 | 74 | 620 | 635 |
| Cracked bean | 872 | 955 | 239 | 358 | 254 | 20 | 295 | 402 | 6 | 2 | 996 | 766 |
| Cracker meal | 902 | 978 | 104 | 351 | 14 | 174 | 57 | 642 | 16 | 4 | 960 | 866 |
| Genipap juice residue | 136 | 965 | 47 | 658 | 556 | 4 | 469 | 445 | 342 | 51 | 812 | 644 |
| Grape wine residue | 892 | 937 | 121 | 861 | 502 | 74 | 458 | 285 | 393 | 315 | 521 | 398 |
| Guava juice residue | 286 | 986 | 86 | 268 | 189 | 77 | 730 | 94 | 581 | 221 | 360 | 383 |
| Jack fruit | 342 | 925 | 108 | 830 | 444 | 34 | 427 | 356 | 387 | 19 | 792 | 666 |
| Jack fruit silage | 278 | 960 | 83 | 381 | 159 | 17 | 161 | 698 | 97 | 36 | 917 | 765 |
| Mango hull | 204 | 976 | 42 | 974 | 227 | 40 | 366 | 528 | 227 | 59 | 771 | 683 |
| Mango internal seed | 512 | 980 | 55 | 756 | 140 | 78 | 256 | 591 | 38 | 16 | 966 | 787 |
| Mango juice residue | 345 | 976 | 51 | 792 | 226 | 40 | 326 | 560 | 226 | 73 | 753 | 681 |
| Mango outward seed | 349 | 972 | 21 | 565 | 255 | 7 | 674 | 271 | 606 | 136 | 392 | 481 |
| Manufactures of soap (palm) | 945 | 943 | 201 | 760 | 244 | 115 | 533 | 94 | 465 | 280 | 518 | 380 |
| Palm meal | 929 | 976 | 121 | 866 | 225 | 164 | 628 | 63 | 539 | 83 | 629 | 565 |
| Papaya juice residue | 101 | 949 | 148 | 869 | 274 | 73 | 294 | 435 | 287 | 77 | 961 | 652 |
| Papaya seed | 802 | 929 | 259 | 902 | 723 | 229 | 156 | 284 | 134 | 75 | 929 | 642 |
| Papaya without seed | 881 | 936 | 133 | 522 | 51 | 21 | 120 | 662 | 161 | 44 | 676 | 754 |
| Passion fruit | 195 | 963 | 100 | 180 | 77 | 122 | 548 | 194 | 419 | 78 | 687 | 591 |
| Peach palm | 865 | 950 | 60 | 243 | 118 | 13 | 578 | 299 | 389 | 30 | 714 | 643 |
| Pearl millet | 892 | 984 | 178 | 851 | 426 | 39 | 205 | 563 | 12 | 12 | 946 | 787 |
| Pineapple crown | 140 | 922 | 91 | 115 | 60 | 15 | 522 | 293 | 266 | 33 | 783 | 626 |
| Pineapple hull | 95 | 959 | 66 | 453 | 80 | 5 | 509 | 381 | 247 | 27 | 830 | 678 |
| Pineapple juice residue | 139 | 953 | 71 | 505 | 444 | 8 | 602 | 272 | 310 | 37 | 811 | 616 |
| Protein bran | 858 | 942 | 219 | 382 | 133 | 28 | 227 | 468 | 96 | 14 | 910 | 754 |
| Pumpkin seed | 173 | 956 | 176 | 359 | 271 | 20 | 196 | 564 | 141 | 33 | 946 | 740 |
| Radish biofuel residue | 916 | 943 | 276 | 199 | 187 | 243 | 227 | 197 | 145 | 75 | 816 | 676 |
| Rice hull | 919 | 839 | 21 | 917 | 599 | 7 | 691 | 120 | 751 | 199 | 91 | 275 |
| Soursop juice residue | 260 | 977 | 104 | 421 | 283 | 131 | 378 | 365 | 311 | 72 | 826 | 660 |
| Soybean hull | 922 | 956 | 120 | 696 | 254 | 4 | 675 | 156 | 454 | 16 | 928 | 646 |
| Sunflower biofuel residue | 927 | 949 | 369 | 118 | 56 | 21 | 186 | 372 | 113 | 52 | 882 | 730 |
| Tamarind juice residue | 466 | 975 | 131 | 388 | 340 | 26 | 531 | 286 | 252 | 117 | 738 | 544 |
| Uricury bran | 891 | 969 | 138 | 791 | 464 | 48 | 683 | 100 | 557 | 234 | 657 | 356 |
| Wild cabbage residue | 806 | 914 | 184 | 486 | 227 | 11 | 257 | 462 | 210 | 22 | 946 | 699 |
| Wild cabbage stalk | 77 | 858 | 183 | 402 | 239 | 11 | 316 | 348 | 233 | 45 | 900 | 591 |

[a]g/kg; [b]g/kg in DM; [c]g/kg in CP

Dry matter (DM); organic matter (OM); crude protein (CP); neutral detergent insoluble nitrogen (NDIN); acid detergent insoluble nitrogen (ADIN); ether extract (EE); neutral detergent fiber expressed exclusive of ash and nitrogenous compounds [aNDFom(n)]; non-fibrous carbohydrate (NFC); acid detergent fiber expressed exclusive of nitrogenous compounds (ADF(n)); lignin (LIG); in vitro neutral detergent fiber digestibility (IVNDFD); total digestible nutrients (TDN).

Table 2. Descriptive statistics and distributions of two groups formed from the discriminate analysis of by-products

| Variables | Mean | SD | Minimum | Maximum | CV (%) |
|---|---|---|---|---|---|
| | | | IVNDFD, g/kg DM | | |
| Group 1 | 425 | 194 | 91 | 657 | 45.7 |
| Group 2 | 814 | 119 | 579 | 996 | 14.7 |
| | | | TDN, g/kg | | |
| Group 1 | 388 | 62 | 275 | 481 | 16 |
| Group 2 | 663 | 97 | 446 | 881 | 14.7 |

In vitro neutral detergent fiber digestibility (IVNDFD); total digestible nutrients (TDN).
Group 1 = Cassava stalk, castor bran, coffee hull, coffee parchment, grape, guava, mango seed outward, manufactures of soap (palm), Rice hull, uricury bran.
Group 2 = African meal, barbados cherry, brewer residue, carrot discard from human residue, carrot leaf, carrot shaving, carrot thick residue, cassava dirty hull, cassava flower processing, cassava foliage, cassava hull of the thread, cassava hull, cassava leaf, cassava shaving, castor detoxicated bran, citrus pulp, cocoa bran, cocoa seed hull, cotton bran, cotton seeds, cracked meal, cracker, genipap, jack fruit silage, jack fruit, mango fruit from juice industry residue, mango hull, mango internal seed, palm, papaya fruit from juice industry residue, papaya seed, papaya without seed, passion fruit from juice industry residue, peach palm, pearl millet, pineapple crown, pineapple hull, pineapple, protein bran corn, pumpkin, radish biofuel residue, soybean hull, sunflower biofuel residue, tamarind fruit from juice industry residue, wild cabbage residue, wild cabbage stalk.

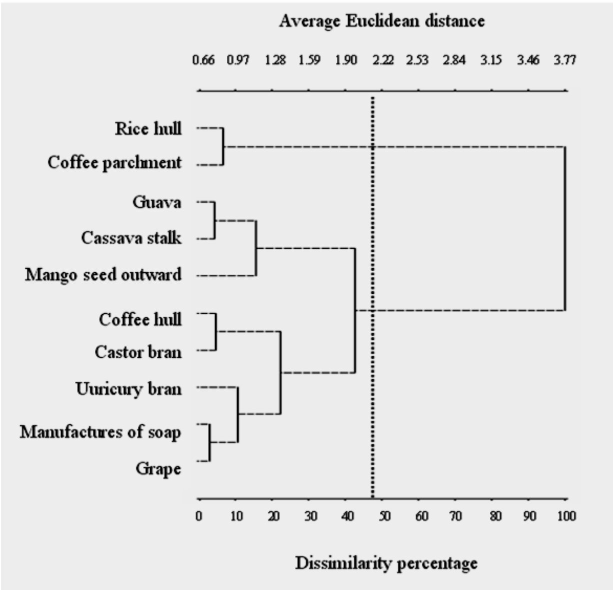


Figure 1. Dissimilarity dendogram of the nutritional value between 10 by-products.

The two subgroups were formed by considering 48% of the dissimilarity due to the short distance between the melting points of the groups by performing a section of the dendrogram as presented in Figure 1, carried out subjectivly according to Johnson and Wichern (1988). In these two subgroups, by-products of rice hull and parchment coffee were hierarchically clustered in a different subgroup compared to the other G1 by-products since they exhibited low IVNDFD and TDN values (Table 1).

Clustering techniques minimize the variability within a group. However, if the estimate of the distance between pairs of individuals within a group is high, sub-clustering is justified (Abreu *et al*., 2004). Due to the large number of discriminatory variables, sub-clustering better stratifies the by-products of G2. As the by-products of G2 represented 82.5% of all the by-products studied, a new cluster analysis was performed using the following as discriminatory variables: ACP, EE, NFC, aNDFom(n), LIG, IVNDFD, and TDN (Figure 2). Subsequently, this hypothesized section in the dendogram of dissimilarity improved the characterization of G2 through the formation of six subgroups (SG1 to SG6).

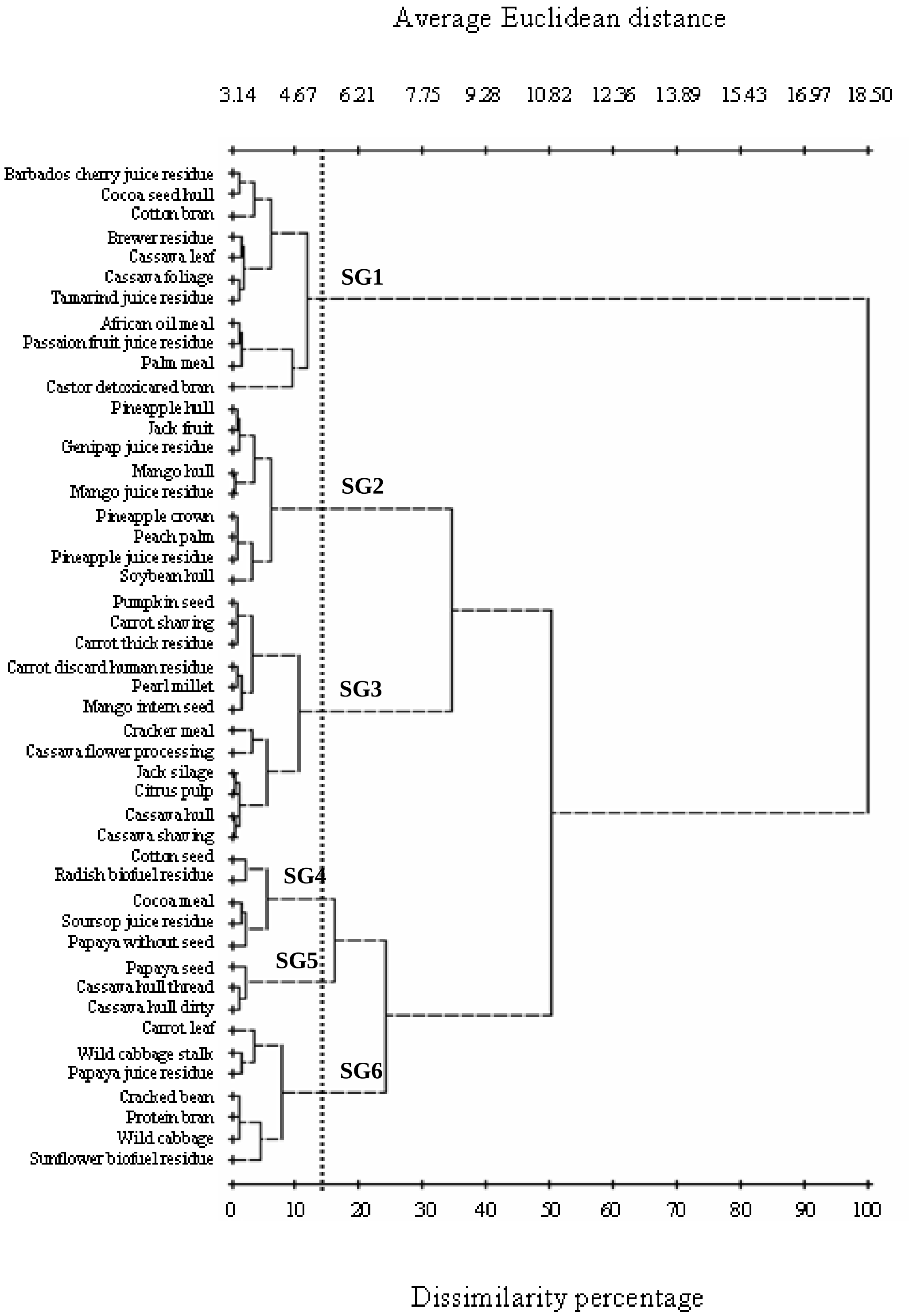


Figure 2. Dissimilarity dendogram of the nutritional value of 47 by-products.

Although SG1 by-products had the second highest average protein values amongst the subgroups, and the highest content of ACP (castor bean detoxicated with 389g/kg of ACP in DM), they also had the highest and the lowest value, respectively, for LIG and TDN (Table 1). SG1 was the most heterogeneous subgroup, which had by-products with the highest average Euclidean distance of 4.23 (Figure 2). However, the discriminatory variable that most influenced the cluster analysis was TDN, which was substantiated by the coefficient of variation (CV) of 6.16% obtained by the same subgroup (Table 1). SG2 by-products had the highest average values of aNDFom(n) and values greater than 600 and 700g/kg of TDN and IVNDFD, respectively (Table 1). SG3 by-products had the highest average values for TDN (772g/kg) and IVNDFD (934g/kg) and the lowest average value for LIG (23g/kg in DM). Among the discriminatory variables, EE content mostly influenced the hierarchical grouping of by-products in SG4 (Table 1).

The three by-products of SG5 were very homogeneous and had the highest concentration of NFC. The main characteristic that distinguished SG5 was lower values of IVNDFD. However, the by-products of this subgroup are essentially energy. Differently from the other subgroups, SG6 by-products had the highest average ACP value, suggesting their use as protein concentrates (Table 1).

## DISCUSSION

The low digestibility of NDF in the by-products of G1 for rice hull and parchment coffee was mainly due to the high concentration of LIG, as LIG is one of the main limiting factors of fibrous carbohydrate digestion (Jung and Allen, 1995).

In addition to the factors inherent in the chemical composition of the fiber fraction and in addition to LIG operating as the main limiting factor in the availability of its chemical contents, other factors also interfere with a better usage of the nutritional value of the other by-products of G1.

In general, the by-products belonging to SG1 group had high aNDFom(n) values, which resulted in lower energy content. Due to the high degree of association of aNDFom(n) to LIG, a lower residue availability was observed, thus reducing the fraction of the feed that could potentially be digestible.

In our present study, all SG1 by-products had TDN values below 600g/kg and NDFap values greater than 300g/kg in DM. This finding is supported by results from other researches that have already tested the by-products classified in our SG1 as roughages.

Modesto *et al*. (2008) concluded that up to 600g/kg of cassava foliage silage can be substituted for corn silage in the diets of non-lactating cows without modifing consumption, ruminal parameters, or nutrional digestibility. Cabral Filho *et al*. (2007), evaluating possible alterations in feed intake and digestibility by substituting an exclusively hay only diet with wet brewer´s grain (a silage by-product) in sheep, observed that the inclusion of 330g/kg of this by-product stored based on DM improved the digestibility of the diet and thereby demonstrated the usefulness of this feed resource.

As can be seen in Table 1, all representative by-products of SG2 had CP values below 200g/kg in the DM, and, in spite of having NDFap values greater than 320g/kg, all can be considered partial energy concentrate substitutes.

Among the SG2 by-products, the soybean hull obtained from soybean milling has been greatly highlighted in the national scenery due to high Brazilian soybean production. The soybean hull represents 70-80g/kg of the bean's weight (Restle *et al*., 2004). Due to its high NDF content, the soybean hull was initially evaluated as a roughage substitute in diets (Azevedo, 1998). However, results confirming the high digestibility of NDF in this residue led to studies of the use of soybean hull as a substitute for cereal bran in the concentrated fraction of the diet (Bach *et al*., 1999).

Animals that receive diets containing soybean hull, partially substituting for corn or sorghum, have demonstrated high levels of diet fiber digestion (Mendes *et al*., 2005) and have demonstrated improvement in weight gain and feed conversion (Restle *et al*., 2004). Additionally, this residue resulted in high production of volatile fatty acids (Bach *et al*.,

1999) and in ideal pH supporting the action of ruminal microorganisms (Ludden *et al*., 1995).

Since high energy contributions supporting ruminal microorganisms were found for SG3 by-products, a protein source of compatible degradation rate should be considered when formulating diets with these by-products. Synchronization of energy fermentation and CP degradation is essential for efficient use of energy and protein by ruminal microorganisms.

Assis *et al*. (2004), substituting corn meal for citrus pulp in the diet of milking cows, observed that the apparent digestibility of the nutrients did not vary with the substitution. The authors explained their finding as a result of the high degradability of citrus pulp fiber preventing differences in the digestibility of the nutrients.

Studies conducted by Milton and Brandt (1993) and Passini *et al*. (2001) have shown that 300g/kg of crack meal can be substituted for corn in ruminant diets. However, since this residue in our present study presented 174g/kg of EE in DM (Table 1), it is advised that attention be paid to EE content of any diet. As dietary proportion of lipids exceeds 60g/kg in DM, they may cause negative effects on ruminal environment, including reduction in fiber digestibility (Palmquist and Jenkins, 1980).

Care should be taken with all by-products in SG4 as this subgroup demonstrated the highest average value of EE with soursop juice residue possessing the lowest value (131g/kg in DM).

In a study that compared levels of 0, 120, 180 and 240g/kg of cotton seed in feedlot diets, Brosh *et al*. (1989) concluded that this residue caused a reduction in weight gain without a change in DM intake. Ludovico and Mattos (1997) observed a quadratic effect of cotton seed (i.e., 0, 100, 200 or 300g/kg) on DM intake in cows on sugar cane and cotton seed diets. Cooke *et al*. (2007) reported that diets containing cotton seed did not affect DM intake or milk production, but they did reduce milk fat content due to reduced unsaturated lipids. Therefore, it is suggested that the use of SG4 by-products be limited due to their EE concentration.

Several of the SG5 by-products with NFC concentrations of 707g/kg in DM have been tested as partial substitutes for energy concentrates. Marques *et al*. (2000), studying the effect of cassava hull as a substitute for corn, observed that, although cassava hull reduced DM intake, it did not alter weight gain, feed conversion, or income from the animals' carcasses. However, they suggest caution with the substitution to avoid problems with intake and acidosis.

With average CP values of 212g/kg in DM, SG6 by-products have been evaluated as partial substitutes for protein concentrates (Table 1). Studies involving young ruminants and milking cows have indicated that the nutritional value of sunflower meal is equivalent to soybean and cotton meal (Vincent *et al*., 1990; Milton *et al*., 1997). Macedo *et al*. (2003), substituting soybean meal for corn gluten, observed a reduction in the production of milk, fat, NDF intake, and plasmatic urea levels.

Considering that soybean meal is the main and most used protein ingredient in ruminant rations, limitations on partial substitution should be imposed due to soybean meal offerring a better biological protein value when compared to other by-products, which are typically inferior due to their inbalance of essential amino acids. Additional factors such as low palatability and low digestibility of the cracked beans should also be considered.

As can be seen in Table 1, the lowest CP value among SG6 by-products was for carrot leaf at 145g/kg in DM. Carrot and wild cabbage by-products have high mineral content, resulting in ash in DM values of 362 and 142g/kg, respectively.

## CONCLUSION

Results support the hypothesis that the by-products belonging to G1 had limited characteristics for their use in animal feeding. The SG1 by-products could preferably be used as partial roughage substitutes. The by-products of subgroups SG2, SG3, SG4, and SG5 could be used as partial energy concentrate substitutes, and the SG6 by-products could be used as partial protein concentrate substitutes.

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