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Locally Produced Agricultural By-Products as Feed Sources for Pigs

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Abstract

Raw fiber concentrates, products with high content in cellulose, hemicellulose and lignin, are new sources of concentrates with high biological and functional value. Recent studies have demonstrated that raw fiber concentrated products have a positive influence on intestinal development, in health status of piglets and in sows. Agricultural by-products with high lignocellulose content are commonly used as supplementary feeds for animals and with their low or zero cost can also improve the economic efficiency of animal production. The materials that have been studied in this work currently are wasted or in best case are used as pellets fuel.

In order to explore these potentials a series of by-products were investigated: walnut shell, olive kernel, grape branches, woody parts of oregano, corn cobs, corn stalks, woody parts of potato, cotton stems, sawdust mix of oak, spruce and pine and cottonseed fiber. The quality of those by-products is evaluated after a series of classical feed analysis. Samples were collected from the region of Thessaly in Greece. The chemical composition of these by-products was determined in order to develop a proper feeding system for livestock. Our results showed high availability and lignocellulose content in a lot of by-products. These should be used to produce concentrated raw fiber feeds in order to improve the animal production and farmers' livelihood.

Introduction

The intensive system of livestock production and the high cost of conventional feeds have aroused interest in the search for cheaper feedstuffs as substitutes. Agro-industrial by-products which are generated in large amounts every year would be an excellent choice in conventional diets for the animals due to their availability, their low cost, and their constituents (proteins, minerals, vitamins and trace elements). Countries according to the environmental legislation should seriously take into consideration the economic benefits that result from the use of these by-products [1-4]. Several studies have demonstrated that when sows are fed with raw fiber (high content in cellulose hemicellulose and lignin) there is a positive influence on their health status [5-7].

Cellulose is a major structural component of plant cell walls, which is responsible for mechanical strength. It is made up of a linear polymer chain, which in turn consists of a series of hydroglucose units in glucan chains. The hydroglucose units are held together by 1-4 glycosidic linkages, producing a crystalline structure that can be broken down more readily to monomeric sugars. Hemicellulose macromolecules are repeated polymers of pentoses and hexoses and thus can be a source of various polysaccharides, like xylose, galactose, mannose and arabinose. It has been also reported [8] that hemicellulose water holding capacity is greater to that of cellulose. Lignin is a complex polymer of aromatic alcohols known as monolignols. Lignin contains three aromatic alcohols (coniferyl alcohol, sinapyl alcohol and coumaryl alcohol) that are produced through a biosynthetic process and forms a protective seal around the other two components [9-11].

Feeds may be classified as concentrates and roughages, depending on their composition. Concentrates contain a high density of digestible nutrients (crude fiber content less than 18% of dry matter). The term raw fiber concentrates describes raw fiber ingredients with at least 60% raw fiber content. This is mostly achieved by the use of concentration processes, which can be of a physical or thermo-mechanical nature. Raw fiber concentrates are new sources of fiber concentrate with high biological and functional value; they can be mixed in concentrated high-energy ratio for sows and they increase the fiber content of the diet without significantly reducing its energy content [12-14]. The beneficial effects of high-fiber concentrated feedstuffs have been shown in several studies [15,16]. High fiber diets appear to promote resting behavior in sows and indirectly results in a reduction in aggressive behavior in group housing systems [17-23]. Dietary fiber has been shown to prolong postprandial satiety, to increase welfare and to reduce stereotypic behaviors in pigs by reducing feeding motivation [24]. Raw fiber has a satiation effect on sows, which in turn has a calming effect. Therefore the addition of raw fiber to the diet reduces aggressive behavior and fights when pregnant sows are housed in groups. The water holding capacity (WHC), describes the ability of feed to bind water under atmospheric pressure and it is particularly important for effective digestion. In addition raw fibers reduce the feed intake in *ad libitum* feeding systems in order to prevent too much weight gain. Therefore the satiation effect occurs very quickly and with the dosage of raw fiber concentrates the desired feed intake can be regulated [17]. Also, calves fed with raw fiber concentrate had better fecal score than the control group in the entire experimental period. These observations could be due to the increased role of raw fiber concentrate in peristalsis movements of

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intestine; raw fiber contents in sow can speed up the intestinal transit time of the digestion by up to 40% [25]. Dietary (raw) fiber is also the main substrate of intestinal bacteria. Pig's microbiota contains highly active cellulolytic bacterial species, including *Fibrobacter intestinalis*, *Butyrivibrio* spp., *Ruminococcus* spp. [26,27]. Soluble (pectins, gums, β-glucans) and insoluble (cellulose) dietary fibers can be degraded by intestinal bacteria producing volatile fatty acids; when they are absorbed from the large intestine they may provide up to 30% of the energy requirement for maintenance in growing pigs [28]. The higher fermentability of soluble fiber can be attributed to its higher water-holding capacity allowing bacteria to easily penetrate the matrix and start degradation. Thus, with diets containing high soluble fiber levels, the activity of bacteria with cellulolytic and hemicellulolytic activities is generally increased [29].

In addition to the benefits that result from the raw fiber use, some of these by-products are also a source of fats and minerals. In particular, fats can be utilized not only to provide energy but fat-soluble vitamins and essential fatty acids. Also minerals are necessary to maintain body function, to optimize growth and reproduction and to stimulate immune response [30-32]. Another significant parameter of an animal feed is acid binding capacity (ABC) since it can affect the procedure of digestion. Different components in animal feed can change the ABC of the feed, which is important in pigs and poultry. Feed components with high ABC values can absorb a lot of H^+. As a result the pH of the stomach and the proximal digestive tract will remain high [33,34]. Local agricultural by-products could be used for the production of concentrated raw fiber products for animal diet. Initially, the objective of this study was to identify agro by-products available for livestock feeding as well as to suggest the most suitable by-product or by-product combination that fits the characteristics of the commercially available products.

Materials and Methods

Materials

The agricultural by-products that used for the research work were obtained during 2013-2014 from the region of Thessaly in Greece. The following by-products were investigated: walnut shell, olive kernel, grape branches, woody parts of oregano, corn cobs, corn stalks, woody parts of potato, cotton stems, sawdust mix of oak, spruce and pine and cottonseed fiber. Acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin, ether extract (EE), ash content, pH, acid binding capacity (ABC) and water holding capacity (WHC) were determined.

Methods

The samples initially were purified from impurities, little stones and tracks of dust. Laboratory sample preparation was needful in order to convert the sample into a homogeneous material suitable for analysis. Before grinding, the biggest parts of samples were cut and divided in smaller. Drying samples grinded in a mill (System POLYMIX® PX-MFC 90 D) into smaller particles using sieve with 1-2 mm wide openings [35]. Drying of samples (approximately 2 g) was obtained by heating in a drying oven (model R. Espinar, S.L.) at 100-103 °C until constant weight was obtained between two sequential measurements [36].

pH measurements were made using a digital laboratory pH meter (model WTW pH 525) which was calibrated using certified pH=4.0 and pH=7.0 buffer solutions, according to official method [35]. About 10 g of each sample were weighted and swirled in 90 ml of distilled water for 30 min and after standing the pH was measured. The ether extract (EE) was determined using method of Soxhlet. Approximately 5 g of solid sample were mixed with anhydrous sodium sulfate, placed in an extraction thimble and were extracted using an appropriate solvent in the Soxhlet extractor. The distilled solvent was condensed and in final drying step the remaining traces of solvent was evaporated from the boiling flask. The mass of the extract (total fat) was measured after subtracting initial from final weight of the boiling flask [37]. Ash contents were determined using dry ashing method. The samples (5 g) were ashed for about 8 hr until a white or grey ash residue had been obtained using a furnace (model P. Selecta, 3000 W) where temperature had been gradually increased from room temperature to 450 °C in 1 h [36].

Acid detergent fiber (ADF), neutral detergent fiber (NDF) and lignin were determined according to [37] using an extraction unit for determining raw fiber content (model DOSI-FIBER-P. SELECTA). NDF is the amount of substances obtained from residue after boiling of sample (1-2 g) with neutral detergent solution. NDF residue contains hemicellulose, cellulose, lignin, cutin, insoluble mineral substances and some proteins of cell walls. ADF is the amount of substances obtained from residue after boiling of sample with acid detergent solution. ADF residue contains cellulose, lignin, cutin and by mineral substances insoluble in an acid environment (silica). The difference between NDF and ADF is given mostly by hemicelluloses.

ABC was calculated as the amount of acid in milliequivalents (meq) required lowering the pH of 1 kg of sample to pH 4.0 (ABC-4). The acid binding capacity was measured according to [38]. A 10 g sample was suspended in 90 ml of distilled water and continuously stirred with a magnetic stirrer. Titrations were performed by addition of acid (0.1 N HCl) in variable increments. Acid was added so that it would take approximately 10 separate additions of acid to reach pH 4.0. Initial pH and all further readings taken during the titration were recorded after equilibration for three minutes [33,39]. Water holding capacity (WHC) was analyzed using an adaptation of the filtration method [40]. A dry sample 0.5 g was soaked in 200 ml of distilled water for 24 h at room temperature and then filtered through Whatman No.1 filter paper. Samples were filtered rapidly and filtration was completed after 10 min. A sample of the residue was weighed (wet weight) before drying overnight in an oven at 105 °C and reweighed (dry weight) which gave WHC.

Thirty samples have been analyzed for the data present in Table 1 (three samples for each by-product). Twenty one samples have been analyzed for the data present in Table 2 (three samples for each by-product).

Statistical analysis

Initially, all data from the analyses previously described were summarized. Then, the medians of the ADF, NDF and lignin percentage were compared among all the agricultural by-products considered by the K-sample equality-of-medians test. The same test was used to compare the medians of the WHC, pH and ABC among

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Table 1: Chemical characterization (median (range)) of the investigated by-products.

By-product	EE	ADF	NDF	Lignin	ASH
Walnut Shell	0.7 (0.6,0.8)	52.7 (50.6,54.7)	77.3 (75.3,79.4)	36.7 (33.8, 39.5)	3.2 (2,4.5)
Olive Kernel	8.4 (7.9,8.9)	43.0 (40.8,45.2)	59.3 (55.1,63.5)	27.0 (24.4, 29.6)	3.4 (2.1, 4.6)
Grape Branches	1.5 (1,2)	42.0 (39.8,44.2)	67.0 (64.8,69.2)	27.7 (25.1,30.2)	1.5 (1.1,2)
Woody Parts of Oregano	1.4 (0.8,1.9)	46.0 (43.1,48.9)	77.3 (75.3,79.4)	22.3 (19.8,24.8)	2.1 (1.3,3.0)
Corn Cobs	1.4 (0.9,1.9)	42.7 (40.6,44.7)	82.5 (80.5,84.5)	27.0 (24.4,29.6)	1.3 (0.9,1.8)
Corn Stalks	1.5 (1.0,2.1)	46.3 (43.7,48.9)	60.7 (56.5,64.8)	13.3 (10.4,16.2)	3.1 (2.3,3.9)
Woody Parts of Potato	0.7 (0.4,0.9)	58.0 (55.8,60.2)	77.3 (75.3,79.4)	32.0 (30.1,35.2)	0.7 (0.6,0.8)
Cotton Stems	1.5 (1.5,1.6)	46.7 (44.3,49)	84.0 (80.6,88.8)	33.3 (30.4, 36.2)	1.7 (1.2,2.1)
Sawdust Mix of Oak Spruce and Pine	1.4 (0.9,1.9)	58.3 (56,60.7)	82.3 (80.3,84.4)	27.3 (24.8,29.8)	1.5 (1.0,1.9)
Cottonseed Fiber	0.4 (0.3,0.5)	ND	87.3 (85.6,89)	ND	0.8 (0.6,0.9)

ND=Not Detected

Table 2: Median (range) of the acid binding capacity (ABC), water holding capacity (WHC) and pH of the investigated by-products.

By-product	Walnut Shell	Olive Kernel	Woody Parts of Oregano	Corn Stalks	Woody Parts of Potato	Cotton Stems	Sawdust Mix of Oak Spruce and Pine
ABC (ml HCl)	3.2 (3,3.3)	3.1 (3,3.2)	14.5 (13.9,14.8)	10.5 (10.3,10.9)	14 (13.9,14.2)	23.8 (23.5,24.9)	3.6 (3.5,3.8)
WHC (g water/ g sample)	1.4 (1.3,1.4)	2.2 (2.1,2.5)	5.8 (5.7,6.1)	6.4 (6.1,6.5)	6 (5.8,6.2)	7.2 (7,7.3)	4.2 (4.1,4.3)
pH	6.1 (6.0,6.2)	4.4 (4.3,4.6)	5.8 (5.7,6.1)	5.4 (5.3,5.7)	6.0 (5.7,6)	6.5 (6.4,6.6)	4.4 (4.3,4.8)

the by-products evaluated. Due to the small sample sizes, the p-values of the above test were calculated by the Fisher's exact method. All analyses were performed in Stata 13.1 (Stata Statistical Software, College Station, TX) and evaluated at the 5% level of significance.

Results

Contents of by-products that have been studied in this work have shown a variety of characteristics as it is demonstrated in Table 1. For EE, ADF, percent lignin and ash no median of any by-product analyzed differed (lowest p=0.12) from the respective overall medians of 0.99,47,29 and 1.8. In contrast, NDF medians differed (p=0.002). The medians of NDF in corn cobs, cottonseed fiber, cotton stems and sawdust mix of oak spruce and pine were higher than the overall NDF median of 79.4.

EE content was similar in lot of by-products (corn stalks, cotton stems, corn cobs, sawdust mix of oak spruce and pine), while the higher percentage is observed in olive kernel (8.5%) and lower in cottonseed fiber (0.4%). The measurement for lignin, ADF and NDF content has varied from not detected (ND) to 40%, ND to 58% and 59 to 87% respectively. The higher values of lignin, ADF and NDF were observed in walnut shell (36.7%), in sawdust mix of oak spruce and pine (58.3%) and cottonseed fiber (87.3%) respectively while lowest contents have been observed in cottonseed fiber (ND), cottonseed fiber (ND) and olive kernel (59%) respectively.

The ash content (minerals) was less than 3.4% for all samples that have been analyzed with the higher value has been observed in olive kernel (3.4%) and the lowest in woody parts of potato (ND).

In Table 2 the medians (range) of WHC, pH and ABC for the by-products that were analyzed were presented. The median WHC of cotton stems, corn stalks and woody parts of potato was higher (p=0.001) than the overall median WHC of 5.8. Cotton stems, woody parts of oregano and woody parts of potato had higher (p=0.001) median ABC than the overall ABC of 10.5. Lastly, the median pH of cotton stems, walnut shell and woody parts of potato was higher (p=0.01) than the overall median pH of 5.8. The measurement for ABC, WHC, pH measurements were varied from ND 3.1 to 23.8, 1.4 to 7.2 and 4.4 to 6.5 respectively. The higher values of ABC, WHC, pH were observed in cotton stems (23.8), cotton stems (7.2) and cotton stems (6.5) respectively while lowest values were observed in olive kernel (3.1), walnut shell (1.4) and olive kernel (4.4) respectively.

Analysis of feed parameters presented in Table 2 was not necessary for all by-products presented in Table 1. Only seven by-products have been selected for analysis of parameters presented in Table 2 (ABC, WHC and pH). The selection was based primary in their amount produced in the region as well as their close relation with other by-products presented in Table 2. Grape branches have not been analyzed because are not produced in large amounts in the region. Cottonseed fibers and corn cobs have not been analyzed because they have close relation (same plant) with cotton stems and corn cobs respectively that both are presented in Table 2.

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Discussion

Our data reveal a variety in cellulose, hemicellulose and lignin content (Table 1) as those are reflected from ADF, NDF and lignin values respectively. We also observed significant differences in other characteristics such as ABC and WBC in feeds (Table 2). The variety of feed values of those by-product provide an excellent starting point for formulation of products with different characteristics and contents that could satisfy the different feed needs of different age groups of pigs. In particular the most promising by-products seem to be cotton stems, corn cobs, cottonseed fiber and the sawdust mix of oak spruce and pine.

Results from this work clearly demonstrate the high row fibers content that many by-products possess. Due to their availability and low cost, walnut shell, woody parts of potato, corn stalks and cotton stems can be used as additives developing a proper feeding system for livestock. Their high cellulose content (>60%) and the presence of minerals give an alternative solution to the farmers to use these products in order to improve the animal production. It is demonstrated (Table 2) that some feed components bind more acid than others because of their high ABC. Feed components with high ABC values can absorb a lot of H^+. As a result the pH of the stomach and the proximal digestive tract will remain high and the protein breakdown will be impaired in the stomach. In the jejunum and colon, excessive protein fermentation may occur, leading to the formation of toxin biogenic amines [33]. The concept of manipulating stomach acidity using components of low acid-binding or buffering capacity to starter feeds should be applied in our case, adding olive kernel or walnut shell with low values of ABC. It is thought that ingredients of low ABC could then be used to formulate a starter diet in such a way that gastric acidity would be promoted.

The WHC is particularly important in reducing feed intake in *ad libitum* feeding systems in order to prevent too much weight gain; therefore the satiation effect occurs very quickly and in the same time the desired feed intake is regulated [17]. The most promising product regarding this property seems to be the cotton stem with superior WBC than the rest of the by-product followed by corn stalks. By-products with high NDF content can be combined with other by-product with high WBC values to achieve a product with desirable properties for different age groups of pigs.

Also, with by products containing high soluble fiber levels (hemicelluloses), the activity of intestinal bacteria with cellulolytic and hemicellulolytic activities is generally increased. Local agricultural by products such as cotton stems or corn stalks could be an ideal solution in animal feeding. EE is relative low in all samples except from olive kernel, indicating that this particular by-product has higher calories content. The ash analysis reflects mineral content which will require further analysis (individual metals and minerals) in order to be fully appreciated, although a first assumption is that walnut shell and olive kernel would provide much more minerals than other by-products.

All those by-products can be found in significant amount in the region of Thessaly. Cotton is the major agricultural product of the region with corn being the second major product. Mountains are in close proximity and wood processing industries are present in significant numbers in the region. This give a constant supply of sawdust mix since the trees like oak and pine are endogenous species and thrive in the area.

Conclusions

A lot of local agricultural by-products can be used as additives in conventional feeds because of their high content in raw fibers. Concentrated raw fiber products can be produced by a lot of local by-products and benefit environment, local economy and farmers' livelihood. The intensive system of livestock production and the high cost of conventional feeds have aroused several interests in the search for cheaper feedstuffs as substitutes. Producers are continuously looking for ingredients with a value added and local agricultural by-products present a possible solution for animal feed because of their high content in raw fibers. This is currently satisfied with products imported from North Europe. Shipping of those products has economical as well as environmental (carbon footprint) cost. The use of local feeds can preserve and protect the environment and promote the efficiency of natural local resources in land and mountainous areas as well as providing an additional income to local farmers. They can use the agricultural crop by-products as feeds or energy material instead of been considered as useless waste. This product can reduce carbon footprint of both crop and animal production in agriculture sector.

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