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Composition, preservation and digestibility by sheep of wet by-products from the food industry

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ABSTRACT

This study examined the chemical composition, *in vitro* and *in vivo* digestibility, aerobic stability and ensiling capability of the fresh wet fibrous by-products *Aspergillus* residue, soy pulp (okara), pomegranate pulp, grape pulp and avocado pulp. Ensiling was assessed in glass silos, and aerobic stability in open PVC containers. Intake and *in vivo* digestibility were measured in mature male Assaf lambs (four lambs/replicates per dietary treatment) held in individual metabolic cages, and *ad libitum*-fed one of the total mixed rations containing the examined fresh by-product and appropriate supplement. *Aspergillus* residue is an acidic, fibrous by-product, characterized by high *in vivo* digestibility of organic matter (OM, 0.85) and neutral detergent fiber (NDF, 0.95), and high stability under aerobic exposure. Ensiling results give large dry matter (DM) losses (41.2%) and continuous yeast fermentation to ethanol and volatiles. Okara is an acidic, fibrous by-product that is rich in protein (290 g/kg DM), characterized by high *in vivo* digestibility of OM and NDF (0.88 and 0.93, respectively), but low stability under aerobic exposure. It can be ensiled with moderate DM losses (16%), producing butyrate and acetate. Pomegranate pulp contains high levels of soluble phenolics and sugars and its voluntary consumption by sheep is low. When fed to sheep it is characterized by low *in vivo* OM and NDF digestibility (0.44 and 0.20, respectively), and low aerobic stability. However, it can be ensiled with moderate DM losses (20%). Grape is rich in ethanol and avocado pulps in fat content, and both byproducts are rich in lignin content and therefore have low *in vivo* OM digestibility (0.30 and 0.43, respectively) originating from their low NDF digestibility (0.12 and 0.31, respectively). These by-products are characterized by low stability under aerobic exposure. Both by-products can be ensiled without any DM losses or NDF solubilization.

Abbreviations: ADF, acid detergent fiber; CP, crude protein; DM, dry matter; IVDMD, *in vitro* dry matter digestibility; IVNDFD, *in vitro* NDF digestibility; aNDF, neutral detergent fiber; OM, organic matter; TMR, total mixed ration; WSC, water-soluble carbohydrate.

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1. Introduction

Global production and consumption of grape, avocado, pomegranate, soy tofu and milk have risen sharply in recent years, partly due to recognition of their health-promoting potential in humans. According to statistical publications, the global production of grape wine has reached 27 billion liters (Wine Institutional Organization, 2012), pomegranate fruit – 15 million metric tons (MMT) (Fruit Market Reports, 2013), soybean (including soy products) – 284 MMT (Baize, 2013), avocado fruit – 2.0 MMT (Fruit Market Reports, 2013), citric acid – 1.9 million tons (Papagianni, 2007). Enormous quantities of industrially processed by-products are manufactured from these foods, including soy pulp (okara) from the soy milk and tofu industries, grape pulp from wineries, avocado pulp from the avocado oil industry and pomegranate pulp from the fruit juice industry. These by-products usually contain a lot of moisture, are fibrous, and may contain readily fermentable soluble sugars or protein, resulting in spoilage under aerobic conditions; this leads to unpleasant odors and attracts flies, creating an environmental nuisance. Disposal of these wet by-products by drying or burying is not cost-efficient; a better alternative is to use them directly for feeding ruminants. However, processing and availability of grape pulp, avocado pulp and pomegranate pulp are limited to their short harvest season (1–2 mo/yr). Thus, seasonal limitations on the one hand, and high contents of moisture and fermentable nutrients which interfere with preservation on the other, are the main obstacles for standardization of these by-product feeds as continuous and steady ingredients in ruminant rations. Another wet by-product from the citric acid industry – *Aspergillus* residue, which is the end product of sucrose fermentation to citrate by the fungus *Aspergillus niger*, is of scientific interest because its NDF fraction arises from fungal mycelium and cell walls (Papagianni, 2007).

Despite the global production of these five wet by-products, their potential as possible feed for productive ruminants is still mostly unexplored. There are some data in the literature about grape pulp digestibility in sheep (Baumgartel et al., 2007; Besharati and Taghizadeh, 2009), but not its aerobic stability or ensiling characteristics. Supplementation of fresh wet pomegranate pulp (up to 200 g/kg dietary DM) to a conventional calf ration promotes an increase in feed intake, with a tendency toward increased weight gain in bull calves (Shabtay et al., 2008); however, it's *in vivo* digestibility is still unknown. Some data are available on the composition and *in vitro* digestibility of avocado pulp (Skenjana et al., 2006), and the composition of okara (Van der Riet et al., 1989). However, data on preservation and ensiling capabilities of these by-products are scarce. By-products that are rich in soluble phenolics, proteins, fat or microbial residues might be characterized by high *in vitro* digestibility (due to high solubility), although their intake and *in vivo* digestibility by ruminants might be fragmentary (Miron and Ben-Ghedalia, 1987). Therefore, *in vivo* digestibility measurements in ruminants are essential to examining the nutritive value of such by-products. The information gaps for these five by-products led us to study and compare the composition, *in vitro* digestibility, preservation features, ensiling characteristics, voluntary intake and *in vivo* digestibility by sheep of fresh *Aspergillus* residue, grape pulp, pomegranate pulp, okara, and avocado pulp. More specifically, we examined and compared: (i) aerobic stability of these fresh wet by-products during 7 d of aerobic exposure; (ii) effects of ensiling these by-products on their composition, preservation features and *in vitro* digestibility; (iii) voluntary intake and *in vivo* digestibility by sheep of these fresh by-products.

2. Materials and methods

2.1. By-products and their aerobic stability

The by-products examined in this study were freshly obtained from the industrial manufacturers. Okara was supplied by the soybean processing factory Solbar Ltd. (Ashdod, Israel); grape pulp was from Barkan Winery (Kibutz Chulda, Israel); avocado pulp was from the avocado oil manufacturer Grinfeld Ltd. (Rishon-Letzion, Israel); pomegranate pulp was from the fruit juice factory Primor (Kibutz Gat, Israel); *Aspergillus* residue was from the sodium citrate producer Gadot Ltd. (Haifa, Israel). A 2-kg portion of each by-product was frozen at −20 °C until analysis for composition and *in vitro* digestibility. Another 3-kg portion of each by-product was left for 1 wk in three 5-L PVC containers (1 kg each). The containers were covered with paper sheets and stored outdoors at an average ambient temperature of 25 °C, and the contents were mixed twice a day. On d 0, 3 and 7, the containers were sampled (200 g from each) to determine aerobic stability parameters: odor and structural changes, yeast and mold development, changes in pH, soluble sugar content and *in vitro* digestibility.

2.2. Ensiling of fresh by-products

Each fresh by-product was ensiled in individual pre-weighed 1-L glass silos in triplicate. The glass silos were tightly closed with a glass cover and rubber ring held with stretched metal holders that enable the escape of gases while preventing the introduction of air into the vessel. Vessels were weighed and stored for 60 d at room temperature (25 + 2 °C). At the end of the ensiling period, the glass silos were reweighed and then opened for sampling. DM content was determined by drying samples at 60 °C for 48 h. A water extract was prepared from fresh samples by soaking 5 g DM equivalent in 100 g water for 30 min, to measure pH and fermentation end products. Silage samples from each silo were stored at −20 °C for further analyses of composition and *in vitro* digestibility. Recovery and loss of DM, NDF and water-soluble carbohydrate