Waste Management xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Optimization of granular waste production based on mechanical properties

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ARTICLE INFO

Article history:
Received 21 December 2017
Revised 20 January 2018
Accepted 10 February 2018
Available online xxxx

Keywords:
Drying
Durability
Pellet
Particle size
Waste

ABSTRACT

Pellet production of food and agricultural wastes is a suitable method to supply livestock feed. Mechanical properties of pellets play an important role in their handling and transportation. In this study, the mechanical properties of pellets made from waste are investigated. After the pelleting process, the pellets were dried with a laboratory convective hot air dryer until reaching a safe moisture content. The effects of feedstock moisture content (0.54, 0.88, and 1.2 $kg_w\ kg_{DM}^{-1}$), particle size (PS < 0.4, 0.4 < PS<1.2, and 1.2 < PS<2 mm), drying temperature (318, 333, and 348 K) and infrared radiation power of the dryer (0, 500, and 1000 W) on pellet durability, impact resistance, and compressive strength were investigated for two diets. The results showed that the mechanical properties of the pellets increased with decreasing particle size of the raw materials. The feedstock moisture content also affected the durability, impact resistant, and compressive strength of pellets. Moreover, mechanical properties were reduced considerably when the pellets were dried at a high temperature and infrared power. The diet with a lower fat content as well as a lower neutral detergent fiber indicated a higher pellet quality. Furthermore, the combination of raw materials and optimization of pelleting and drying conditions had a significant effect on the quality of the produced pellets.

1. Introduction

Feed costs account for more than 50–60% of the meat production costs. Although feed processing techniques increase livestock performance, they also increase feed prices (Abdollahi et al., 2013). Pelleting of agricultural and food residues has been presented as an appropriate solution to eliminate environmental problems and supply of animal feeds. High transportation and storage costs due to low bulk density and also agricultural waste spoilage due to high moisture content (MC) are the problems involved in using these materials in their original form. The pelleting and drying are two proper processes to solve these problems. The mechanical strength of pellets against compressive and shear stresses and impact force are important factors in the evaluation of pellet quality. The quality of pellet is usually evaluated based on its density and durability (abrasion resistance of bulk pellets). The durability of pellets is the strength to impact force and withstand shear applied during handling and transporting, while a high density of pellet represents a higher energy per unit volume of material, a more economical storage, and a high transport capacity of pellets (Adapa et al., 2013). Pellet fracture during handling, transporting, and storage is a major concern for consumers. Low pellet durability causes problems such as a disruption in pellet feeding mechanism, dust emissions, and an increased fire risk during pellet handling and storage (Temmerman et al., 2006). Therefore, improving the pellet durability in the industry is important in order to enhance pellet quality and minimize the losses. Alarcon et al. (2017) determined the optimal conditions and relation between waste ashes and starch to produce pellets with a high heating value and durability from Puno wastes. They reported that a homogeneous structure of grinding ashes and starch and small PS allow pellets formation with high mechanical resistance.

Feed ingredients combined with the diet influence the pellet quality. During the preparation of raw materials, pelleting, and drying a series of chemical reactions occur due to the moisture, pressure, and heat production (Abdollahi et al., 2013). The chemical properties of the raw materials such as gelatin and lignosulfonates have a positive effect on binding agents as well as the strength and durability of the pellet (Thapa et al., 2015). The protein structure changes significantly with exposure to heat and moisture and thus an irreversible protein denaturation occurs. The MC, heat, and shear force are among the most important factors affecting the denaturation process and residence time. Since

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https://doi.org/10.1016/j.wasman.2018.02.019
0956-053X/© 2018 Published by Elsevier Ltd.

Nomenclature

b	constant regression coefficient
M_f	final moisture content, $kg_w\,kg_{DM}^{-1}$
M_e	equilibrium moisture content, $kg_w\,kg_{DM}^{-1}$
M_i	initial moisture content, $kg_w\,kg_{DM}^{-1}$
m	number of independent variables
N	number of drops, N = 2
n′	total number of pieces after N drops
W_i	initial weight of samples, kg
W_w	weight of water, kg
X_i and X_j	independent variables
V_h	specific air volume, $m^3\,kg^{-1}$
I_R	impact resistance index

Abbreviations

CP	crude protein
CS	compressive strength
CV	coefficient of variable
DF	degrees of freedom
IR	infrared radiation
IRI	impact resistance index
MC	moisture content
MD	dry matter
NDF	neutral detergent fiber
PDI	pellet durability index
PS	particle size
RSM	response surface methodology
SS	sum of square

compression of materials during the pelleting process involves a combination of heat, moisture, shear and residence time, it may lead to protein denaturation in the feed and improved digestion (Abdollahi et al., 2013). Buchanan and Moritz (2009) reported that the PDI improvement when 5% of soy protein isolate or cellulose was added to maize-soy as the broiler diet probably because of the moisture absorption ability of cellulose. Abdollahi et al. (2010) found a lower PDI and hardness for sorghum-based diets compared to maize-based diets.

Mani et al. (2003) reported that MC of materials acts as an agglutinate and increases the particle bonding via van der Waal's forces during the compaction process. Demirbas and Sahin-Demirbas (2004) observed that the strength of the spruce-wood pellets significantly increased with increasing the MC from 7% to 15% (w.b.). Tabil and Sokhansanj (1996) investigated the mechanical properties of pellets produced from fresh alfalfa and reported that the water acted as a binder and created pellets with the highest PDI. Wongsiriamnuay and Tippayawong (2015) investigated the effect of the conditioning process parameters on the properties of the maize residue pellets. They reported that the PDI improved with increasing pressure between 150 MPa and 250 MPa and the temperature in the range of 333–353 K due to the lignin passing from the glass temperature transition line.

Many agricultural materials (especially agricultural straw) formed poor pellets after compaction, which is caused by lack of an understanding of the natural binding characteristics and the interaction of the components that make pellets during the compaction. Heat and moisture cause starch gelatinization and help to bind feed particles together (Mommer and Ballantyne, 1991). Moreover, Hermansson (1979) found that soy proteins still possessed good water-binding characteristics despite being partially or completely denatured. These water-binding characteristics may not result in a greater protein denaturation, but they appear to improve pellet quality. During the process of compacting biomass materials, the natural binders (protein, lignin, starch, and fat) can be activated (softened) in the range of glass transition temperature (Kaliyan and Morey, 2010b). Considering the positive and negative effects of MC on the mechanical strength of the pellets, the MC of raw materials must be optimized before pelleting possess. Fat and MC of biomass reduces the pressure required compression because fat acts as a lubricant film between the feed particles and die during the compression process (Whittaker and Shield, 2017). MC, on the other hand, increases the lignin plasticizes and leads to the creation of stronger bonding between particles. Water is an incompressible material that can reduce the PDI. Soluble sugars crystallized after drying and cooling of pellet form some solid bridged (Mišljenović et al., 2016). The composition of raw materials for the production of pelleted feed is determined according to animal's nutritive demands. However, the chemical composition, texture, and structure of ingredients play a very important role in the quality of the pellets. Thus, it is important to understand the effect of any material from the ingredient composition in order to produce the high-quality pellets. The formed pellets may be of a low quality if the combination of raw materials is technically unacceptable. The compression process can destroy anti-nutritional factors so that nutrients can be absorbed more easily.

In recent years, mechanical properties of various pellets such as rice cultivation waste (Brand et al., 2017), canola and sunflower meal (Čolović et al., 2015), biodegradable waste (Zafari and Kianmehr, 2014), maize residue (Wongsiriamnuay and Tippayawong, 2015), and sawdust straw (Stasiak et al., 2017) have been investigated. However, there is no information available in the literature about the effect of drying operation on the mechanical properties of pellets from a combination of various types of agricultural waste as livestock feed supplements. The main objectives of this study are to investigate the effects of feedstock MC, particle size (PS) of raw materials, air temperature dryer, and infrared radiation (IR) power, formulation on the mechanical (PDI, compressive strength (CS), and impact resistance index (IRI)) properties of pellets produced from food and agricultural waste, and to use response surface methodology (RSM) to determine the optimum conditions of the pelleting and IR-convection drying conditions.

2. Material and methods

2.1. Material preparation

In this study, the residual wastes from the winnowing industries, restaurants, and food industries including straw and broken kernels of wheat, bread, date palm, grape, pomegranate, and potato and soybean meal were used for the experiments. The sugar beet molasses was applied as a binder (Kaliyan and Morey, 2009). All materials were purchased from Dastchin Company (Isfahan-Iran) in granular form. The initial raw materials were graded in three sizes ($PS < 0.4$ mm, $0.4 < PS < 1.2$ mm, and $1.2 < PS < 2$ mm) by Tyler sieves with mesh sizes of #40, #16, and #10 in order to understand the influence of PS on density.

2.2. Proximate analysis

Chemical analysis of the raw materials was carried out by the Chemical Analysis Laboratory (Bu-Ali Sina University). Chemical

Please cite this article in press as: Ghasemi, A., et al. Optimization of granular waste production based on mechanical properties. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.02.019