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Integration Of Local Leafy Forage In Smallholder Pig Farming And Its Implications For The Nutritional Quality Of Pork Jerky With Added Subcutaneous Fat.

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Abstract. Integrating locally produced leafy forage into smallholder pig systems may influence the nutritional quality of value-added meat products. This study evaluated pork jerky manufactured with different levels of added subcutaneous fat using carcasses from pigs raised in smallholder farms where local leafy forage formed part of the diet. Leafy forage and jerky were characterised by proximate analysis. A completely randomized design with five treatments (0, 10, 20, 30 and 40% added subcutaneous fat; R0–R4) and five replications was used. Increasing added fat from 0 to 40% reduced jerky moisture (40.10 to 32.80%), ash (9.92 to 5.42%) and crude protein (41.21 to 24.67%), while crude fat (8.19 to 28.44%) and carbohydrate by difference (0.58 to 8.67%) increased markedly ($P < 0.05$). Thus, subcutaneous fat level is a major lever for modifying the energy density and macronutrient profile of pork jerky. From an agricultural systems perspective, these findings illustrate how carcass utilisation and simple on-farm processing can add value to pigs fed partly on local leafy forage and support small-scale agroindustry. Moderate fat inclusion appears to offer a practical compromise between maintaining protein content and enhancing sensory attributes.

Keywords: Pork jerky; subcutaneous fat; leafy forage; smallholder pig farming; proximate composition; crop–livestock integration.

INTRODUCTION

Farming systems at the level of smallholder households usually do not produce only food crops, but also livestock that use the main products and by products from the same land[1]. Integration of crops and livestock is an important strategy to increase efficiency of land use, reduce production costs, and strengthen household food security[2], [3]. Through this integration, biomass flows from crop fields to animals and returns to the soil in the form of manure, creating a more closed and sustainable system[4], [5].

Within this integrated context, leafy forage produced on farmland plays a central role. Forage can come from dedicated fodder crops or from vegetative parts of food crops that are still suitable as feed[6], [7]. This leafy forage commodity contributes not only to soil cover, water conservation, and soil organic matter, but also serves as a major source of nutrients for livestock[8], [9]. The quality and availability of leafy forage directly influence animal performance, carcass composition, and feed efficiency, thereby linking land management with livestock productivity in a single farming system[10], [11].

One of the livestock species commonly kept in mixed farming systems in several regions of Indonesia is the pig[12], [13]. Pigs can utilize a wide range of feed resources derived from crops, including leafy forage and crop residues, to produce meat and fat with economic value[14]. The use of local leafy forage in pig diets can reduce dependence on commercial feeds, increase feed self sufficiency at the farm level, and add value to crop commodities grown on the land[15], [16]. The body composition of pigs, especially muscle and fat tissues, can therefore be viewed as the biological outcome of using leafy forage and other farm based feeds, and these tissues then become raw material for processed products[17].

Livestock products from smallholder farms are not always marketed as fresh meat[18]. To reduce post harvest losses, extend shelf life, and increase value, meat is often processed into preserved products, one of which is jerky[19]. Processing pork into jerky creates opportunities for small scale agroindustry based on livestock that is directly connected to farm production[20]. In this way, the value chain in agriculture extends from crop cultivation that produces leafy forage, through pig rearing, to the processing of meat into ready to eat products.

The quality of jerky, in terms of nutrient content and consumer acceptance, is strongly influenced by the quality of the carcass used as raw material[21]. One important component of the carcass is subcutaneous fat, which develops during growth and is affected by the balance of energy and protein in the diet. In jerky processing, addition of subcutaneous fat plays a role in shaping flavour, texture, and juiciness, while also determining the energy content and nutrient profile of the final product[22]. From an agricultural systems perspective, the way subcutaneous fat is utilized in jerky can be considered part of product management, that is how farmers and small processors make use of all carcass fractions produced from leafy forage based feeding[23].

Many studies have examined the effects of spices, processing techniques, and storage conditions on the physical, chemical, and sensory properties of jerky from various types of meat[24]. However, studies that specifically evaluate different levels of added subcutaneous fat in pork jerky within the context of smallholder pig farming that uses local leafy forage as part of the feeding system are still limited. Yet such an approach is important to view the linkage between forage management in the field, animal performance and body composition, and the quality of processed products in an integrated way.

Based on this background, the present study was conducted to evaluate the nutritional quality of pork jerky processed with several levels of added subcutaneous fat. The analysis includes moisture, ash, protein, fat, and carbohydrate contents as indicators of jerky nutritional quality. The study is placed explicitly in the context of smallholder pig farming that uses local leafy forage as one component of the diet, so that the findings are expected to provide relevant information for the development of integrated crop livestock systems and small scale agroindustry for pork jerky at the farm level.

MATERIALS AND METHODS

Study location and experimental design

The study was carried out in the meat processing and animal nutrition laboratories of an agricultural university in Indonesia. Pork and subcutaneous fat were obtained from pigs raised under smallholder farming conditions in which local leafy forage was used as one component of the diet.

A completely randomized design with one factor was used. The factor was the level of added subcutaneous fat in the jerky formulation. Five treatments were applied, each with five replications, giving a total of twenty five experimental units. The treatments were as follows.

R0 pork jerky made from lean pork without added subcutaneous fat
R1 pork jerky made from pork with ten percent subcutaneous fat
R2 pork jerky made from pork with twenty percent subcutaneous fat
R3 pork jerky made from pork with thirty percent subcutaneous fat
R4 pork jerky made from pork with forty percent subcutaneous fat

Each experimental unit consisted of a batch of jerky slices prepared from one homogeneous meat and fat mixture according to the assigned treatment.

Materials

The main raw materials were fresh pork and subcutaneous fat taken from the same carcasses in order to reduce variation among animals. The pigs originated from smallholder farms where leafy forage and other farm based feed resources were used in the ration.

Additional ingredients for jerky processing were common table salt sodium chloride at about five percent of the batch weight, palm sugar powder or coconut sugar at about fifteen percent of the batch weight, potable water, and a fixed mixture of spices used in the standard pork jerky formulation of the laboratory. The same amount and type of spices were added to all treatments.

Chemicals and reagents used for laboratory analyses followed the official methods of the Association of Official Analytical Chemists AOAC 2005. They included concentrated sulfuric acid, sodium hydroxide solution, catalysts for protein digestion, fat extraction solvent, standard hydrochloric acid solution, boric acid solution, and acid base indicators.

Leafy forage in the feeding system

Leafy forage used in the smallholder pig farming system was obtained from crops grown on the farmers fields. The crops were cultivated and managed according to local practice. The forage was harvested at the usual cutting age used by the farmers and offered to pigs in fresh form, sometimes after chopping, and combined with other available feed ingredients.

For characterization of forage quality, samples were taken as composite samples from several cutting points in the field so that they represented the forage actually used in the pig diet. The samples were dried in a forced air oven at moderate temperature until constant weight, ground, and stored in airtight containers. The dried samples were analyzed for moisture, ash, crude protein, crude fat, and when required crude fibre according to standard proximate methods.

Pork jerky processing

Fresh pork was trimmed to remove excess visible fat, coarse connective tissue, and any remaining impurities, then washed with clean water and drained. Subcutaneous fat was separated from the skin and underlying tissues, cleaned, and chopped.

Pork and subcutaneous fat were weighed according to the treatment. For R0 only lean pork was used, while for R1 to R4 lean pork was mixed with subcutaneous fat at the prescribed percentages. Pork and fat were minced until a fine and homogeneous meat batter was obtained.

Salt and palm sugar were then added at about five and fifteen percent of the batch weight respectively, along with the spice mixture. The ingredients were mixed thoroughly until a uniform batter was formed. The batter was spread into thin layers on clean trays lined with food grade material.

The formed meat sheets were dried in a hot air oven at about eighty degrees Celsius for approximately eight hours until a dry and firm jerky texture was obtained. After drying, the jerky was cooled to room temperature, placed in temporary sealed containers, and kept at ambient temperature until chemical analyses were conducted.

Proximate analysis of jerky and leafy forage

Proximate analysis of jerky and leafy forage followed AOAC 2005 procedures. For jerky, the parameters measured were moisture content, ash, crude protein, crude fat, and carbohydrate by difference. For leafy forage, the parameters measured were moisture, ash, crude protein, crude fat, and when needed crude fibre and nitrogen free extract.

Moisture content was determined by oven drying. A known weight of sample was placed in a pre dried and weighed container, dried in an oven at about one hundred and five degrees Celsius until constant weight, cooled in a desiccator, and weighed again. Moisture content was calculated from the loss in weight during drying and expressed as percentage of the initial sample weight.

Ash content was determined by incineration in a muffle furnace. A known weight of sample was placed in a pre weighed porcelain crucible, charred gently over a flame and then ashed in a furnace at about four hundred fifty degrees Celsius until a light coloured residue remained. The crucible was cooled in a desiccator and weighed. Ash content was calculated from the weight of the residue and expressed as percentage of the original sample weight.

Crude protein content was determined by the Kjeldahl method. Approximately two hundred milligrams of sample were digested with concentrated sulfuric acid in the presence of a catalyst until a clear solution was obtained. The digest was diluted to a known volume, made alkaline with sodium hydroxide, and distilled. Ammonia liberated during distillation was captured in boric acid solution with mixed indicator and titrated with standard hydrochloric acid. Total nitrogen was calculated from the volume and normality of the acid used in the titration and converted to crude protein by multiplying by the factor six point two five.

Crude fat content was determined by solvent extraction using a continuous extraction apparatus. A known weight of dried sample was placed in an extraction thimble and extracted with an organic solvent for a sufficient period until all fat was removed. The solvent was evaporated, and the remaining fat residue was dried and weighed. Crude fat content was calculated from the weight of extracted fat and expressed as percentage of the sample weight.

Carbohydrate content of jerky was obtained by difference, that is by subtracting the sum of moisture, ash, crude protein, and crude fat percentages from one hundred. For leafy forage, nitrogen free extract could also be calculated by subtracting the sum of moisture, ash, crude protein, crude fat, and crude fibre from one hundred.

Statistical analysis

Data on moisture, ash, crude protein, crude fat, and carbohydrate contents of jerky from the five treatments were subjected to analysis of variance according to a completely randomized design with one factor. The statistical model stated that each observation was the sum of an overall mean, the effect of treatment, and a random error term.

Before performing the analysis of variance, data were checked for normal distribution of residuals and homogeneity of variances across treatments using appropriate statistical tests and graphical inspection. When necessary, simple data transformation was considered and the analysis was repeated.

A significance level of five percent was used to judge treatment effects. When the analysis of variance indicated a significant effect of treatment on a given variable, means were compared using an appropriate multiple range test such as the honestly significant difference test. Results were presented as means plus or minus standard deviation, and mean values within the same column that differed significantly were indicated by different superscript letters in the tables.

Data on the chemical composition of leafy forage were summarized descriptively and presented as means and standard deviations for each measured parameter. These values were used to interpret the role of leafy forage in the feeding system of smallholder pigs that supplied the raw material for pork and subcutaneous fat used in the jerky processing.

RESULTS AND DISCUSSION

Chemical composition of leafy forage

The leafy forage used in the smallholder pig farming system was analyzed in order to describe its nutritive value. The results are presented in Table 1. These values represent the quality of forage produced on farm land and used as a component of the pig diet.

Table 1. Chemical composition of leafy forage used in smallholder pig farming

No	Parameter	Unit	Mean value	Standard deviation
1	Moisture	percent	12.5	0.8
2	Ash	percent	9.2	0.4
3	Crude protein	percent	18.3	0.7
4	Crude fat	percent	3.5	0.3
5	Crude fibre	percent	21.4	0.9
6	Nitrogen free extract	percent	35.1	1.1

A moisture content of about twelve and a half percent indicates that the forage was analyzed in a dried form that is relatively stable and easy to store. The ash content of around nine percent reflects a moderate mineral content, which is influenced by soil fertility and fertilization practices on the farm.

The crude protein content of about eighteen percent is in the moderate to high range for leafy forage and suggests that this material can serve as a meaningful source of protein in pig diets. The crude fat content is relatively low at about three and a half percent, which is typical for forage. Crude fibre content of around twenty one percent indicates that the forage is rich in structural carbohydrates and can support normal digestive function.

The nitrogen free extract fraction of about thirty five percent represents non fibre carbohydrates that can supply energy for the animal. Overall, this composition shows that the leafy forage produced on the farm has acceptable nutritive value and plays a tangible role in linking the crop and livestock components within the same farming system.

Nutrients supplied by this forage, particularly protein and energy, contribute to growth and to the development of muscle and fat tissues in pigs. These tissues then become the raw material for pork jerky, so the quality of the forage is indirectly related to the nutritional quality of the processed product obtained at the farm and small scale processor level.

Chemical composition of pork jerky

The nutritional quality of pork jerky was evaluated based on moisture, ash, crude protein, crude fat, and carbohydrate contents. The effects of different levels of added subcutaneous fat are summarized in Table 2.

Table 2. Moisture, ash, crude protein, crude fat, and carbohydrate contents of pork jerky with different levels of subcutaneous fat

Treatment	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Carbohydrate (%)
R0	40.10 ± 0.88 a	9.92 ± 0.66 a	41.21 ± 0.36 a	8.19 ± 0.78 a	0.58 ± 0.66 a
R1	38.73 ± 0.90 b	9.25 ± 0.40 b	39.40 ± 0.89 b	10.55 ± 1.10 b	2.07 ± 0.25 b
R2	37.15 ± 0.38 c	7.94 ± 0.51 b	37.59 ± 0.52 c	12.49 ± 0.42 c	4.83 ± 0.43 c
R3	35.57 ± 0.83 d	7.30 ± 0.92 c	28.18 ± 0.31 d	22.88 ± 0.63 d	6.07 ± 0.46 d
R4	32.80 ± 0.29 e	5.42 ± 0.37 c	24.67 ± 0.57 e	28.44 ± 0.43 e	8.67 ± 0.80 e

Treatments
R0 jerky made from pork without added subcutaneous fat
R1 jerky made from pork with ten percent subcutaneous fat
R2 jerky made from pork with twenty percent subcutaneous fat

R3 jerky made from pork with thirty percent subcutaneous fat
R4 jerky made from pork with forty percent subcutaneous fat

Table 2 shows a clear pattern. As the proportion of added subcutaneous fat increases from R0 to R4, moisture, ash, and crude protein contents decrease, whereas crude fat and carbohydrate contents increase. All variables show statistically significant responses to the level of added subcutaneous fat.

Moisture content

Moisture content decreases from 40.10 percent in R0 to 32.80 percent in R4. Each increase in the level of subcutaneous fat results in a significant reduction in moisture, as indicated by the different letters in the moisture column.

This decline can be explained physically. Fat does not contain water, so replacing part of the lean meat fraction with fat reduces the proportion of water in the mixture. During drying, water is readily removed from the product, while fat remains relatively stable. As a result, jerky with higher fat content has a lower moisture percentage when expressed on a wet basis.

The observed moisture values, ranging from about thirty three to forty percent, are consistent with the characteristics of semi dry meat products such as jerky. Moisture levels in this range help limit microbial growth and extend shelf life, which is particularly important in rural farming communities where cold storage facilities may be limited. For smallholder farmers, the ability to convert pork produced with leafy forage based diets into jerky with controlled moisture content is a practical way to reduce post harvest losses and increase product stability.

Ash content

Ash content also decreases with increasing levels of added subcutaneous fat. Treatment R0 has the highest ash content at 9.92 percent, while R4 has the lowest at 5.42 percent. Treatments R1 and R2 occupy intermediate positions, and R3 and R4 form a group with lower ash contents.

Minerals are mainly associated with lean tissue and aqueous phases, as well as with added salt. When the proportion of fat in the formulation increases, the relative contribution of lean tissue and water, which contain most of the minerals, decreases. In addition, some water soluble minerals may be lost with drip and evaporative loss during drying.

From an agricultural systems perspective, mineral content in jerky reflects contributions from the diet, including leafy forage, drinking water, and added salt. A reduction in mineral content in the final product should be considered if jerky is promoted as a source of minerals for people in farming areas.

Crude protein content

Crude protein content shows a marked decline from 41.21 percent in R0 to 24.67 percent in R4. Each increment in the level of subcutaneous fat produces a significant reduction, and all treatments differ from one another.

Mathematically, this is expected. As more subcutaneous fat is added, the proportion of lean meat, which contains most of the protein, is reduced. During heating and drying, protein is denatured and some soluble components may be lost with the exudate, while fat remains in the product. Consequently, the amount of protein per one hundred grams of jerky decreases with higher fat addition.

From a nutritional standpoint, this has important implications if jerky is intended as a major source of animal protein in smallholder diets. In a farming system based on leafy forage, proteins present in the forage are converted into muscle tissue in pigs. If, at the processing stage, a large part of the lean fraction is replaced by fat, the benefit of forage protein is not fully expressed in the protein content of the final product eaten by consumers.

Crude fat content

Crude fat content increases sharply as the level of added subcutaneous fat rises. It ranges from 8.19 percent in R0 to 28.44 percent in R4, and each treatment differs significantly from the others.

This pattern is fully consistent with the design of the experiment, where subcutaneous fat was deliberately added to alter the fat content of jerky. Fat contributes strongly to texture, flavour, and aroma, and increases the energy density of the product. However, a high fat content is also associated with concerns about excessive intake of saturated fat and cholesterol in human diets.

In terms of product utilization, subcutaneous fat is a carcass fraction that is sometimes underutilized at the farm level. Incorporating subcutaneous fat into jerky allows farmers and small processors to turn this fraction into part of a higher value product. The quantitative information on fat content obtained in this study can be used to develop practical recommendations, for example defining a level of added fat that still yields good sensory quality without overly increasing total fat content.

Carbohydrate content

Carbohydrate content, calculated by difference, increases from 0.58 percent in R0 to 8.67 percent in R4. Each increase in the level of subcutaneous fat is associated with a significant rise in carbohydrate percentage.

Carbohydrates in jerky mainly originate from the palm sugar added to the formulation and from small amounts of non protein nitrogen free extract in the meat. When moisture, protein, and ash decrease as percentages of the product, the remaining fraction accounted for as carbohydrate becomes relatively larger, even though the absolute amount of added sugar remains constant.

Technologically, carbohydrates, especially sugars, are important in flavour development, sweetness, and browning reactions during drying and storage. In a broader agricultural context, the use of palm sugar or coconut sugar in jerky formulation creates a potential linkage between pig production based on leafy forage and other crop enterprises such as coconut or palm based sap production.

Summary of changes in nutritional composition

To highlight the general trends across treatments, the direction of change for each variable is summarized in Table 3.

Table 3. Summary of changes in nutritional composition of pork jerky with increasing levels of subcutaneous fat

Variable	**Direction of change from R0 to R4**
Moisture	Decreased significantly
Ash	Decreased significantly
Crude protein	Decreased significantly
Crude fat	Increased significantly
Carbohydrate	Increased significantly

This summary emphasizes that added subcutaneous fat is a key determinant of the nutritional profile of pork jerky. Fractions related to lean meat and water tend to decrease, while energy rich fractions, namely fat and carbohydrate, tend to increase.

Implications for crop livestock systems based on leafy forage

When the findings are viewed from the standpoint of an integrated crop livestock system, the sequence of linkages can be described as follows. Leafy forage grown on agricultural land supplies protein, energy, and minerals to pigs. Together with other farm based feed resources, this forage shapes growth and the development of muscle and subcutaneous fat in the animals. These tissues are then processed into jerky whose nutritional composition can be controlled by adjusting the proportion of subcutaneous fat in the formulation.

Decisions at the processing stage, such as how much subcutaneous fat to add, are therefore a continuation of decisions made earlier in forage cultivation and pig feeding. Farmers and small scale processors can use the information from this study to design jerky products that are attractive to consumers while also making efficient use of farm resources and maintaining a reasonable balance of nutrients.

Further research that directly links differences in forage type and quality to carcass composition and jerky quality would strengthen the understanding of how the crop and livestock components interact within a single farming system.

CONCLUSION

This study evaluated the nutritional quality of pork jerky processed with five levels of added subcutaneous fat in the context of smallholder pig farming that uses local leafy forage as part of the feeding system. The chemical composition of the leafy forage indicated moderate protein content, substantial fibre, and a considerable fraction of nitrogen free extract, suggesting that the forage has adequate nutritive value as a feed component and functions as an important agricultural commodity in the pig production system.

Addition of subcutaneous fat in jerky processing had a highly significant effect on the chemical composition of the product. Increasing the proportion of subcutaneous fat from zero to forty percent led to progressive decreases in moisture, ash, and crude protein contents, and to marked increases in crude fat and carbohydrate contents. These patterns were consistent across all measured variables and demonstrate that subcutaneous fat level is a major factor determining the nutritional profile of pork jerky.

From an agricultural systems perspective, the results highlight clear linkages between leafy forage production on farm land, pig rearing as a converter of plant biomass into animal products, and simple agroprocessing in the form of jerky manufacture. Information on the nutritional composition of jerky at different levels of added subcutaneous fat can be used by farmers and small processors to design products that meet consumer preferences for flavour and texture while maintaining an acceptable balance of nutrients.

In practical terms, jerky made with moderate levels of added subcutaneous fat could be considered as a compromise between improved sensory attributes and the desire to preserve a relatively high protein content. At the same time, the use of local leafy forage in pig diets helps reduce dependence on commercial feeds and strengthens the self reliance of farming households.

The present study did not quantify direct relationships between specific types and qualities of leafy forage, carcass composition, and jerky characteristics. Future work that explicitly evaluates the effects of different forage species and management on subcutaneous fat thickness, carcass traits, and jerky quality would be valuable for further integrating crop and livestock components within sustainable smallholder farming systems.

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