Beyond Guacamole

Circular Solutions for Avocado Waste in Ethiopian Animal Nutrition

Arya Rezaei Far, Mirjam Spoelstra, Adolfo Alvarez Aranguiz, Abule Ebro

Public
Report 1580

WAGENINGEN
UNIVERSITY & RESEARCH

Beyond Guacamole

Circular Solutions for Avocado Waste in Ethiopian Animal Nutrition

Arya Rezaei Far[1], Mirjam Spoelstra[1], Adolfo Alvarez Aranguiz[1], Abule Ebro[2]

1 Wageningen Livestock Research
2 Private Consultant

This research was carried out by Wageningen Livestock Research and subsidised by the Dutch Ministry of Agriculture, Fisheries, Food Security and Nature, within the framework of Policy Support Research theme 'Name of Theme' (project number BO-69-002-069).

Wageningen Livestock Research
Wageningen, maart 2025

Report 1580

WAGENINGEN
UNIVERSITY & RESEARCH

Rezaei Far, A., M. Tertio, C. Quarto, 2025. *Beyond Guacamole; Circular Solutions for Avocado Waste in Ethiopian Animal Nutrition.* Wageningen Livestock Research, Public Report 1580.

Samenvatting De productie van avocado's in Ethiopië neemt snel toe door de stijgende wereldwijde vraag naar avocado-olie. Koud persen, de meest gebruikte extractiemethode, genereert echter meer dan 90% afval, wat leidt tot milieuproblemen rond afvalverwerking. Gezien het tekort aan betaalbare grondstoffen voor veevoer in Ethiopië, bieden deze bijproducten een veelbelovend lokaal alternatief. Het gebruik van avocado bijproducten wordt echter beperkt door grote variatie in chemische samenstelling, een hoog gehalte aan sterk verhoute vezels, en antinutritionele stoffen zoals tannines en persine, een stof die in verband wordt gebracht met avocadovergiftiging bij dieren. Deze studie toont aan dat, naast de chemische samenstelling, ook de concentraties persine in de bijproducten sterk variëren. Door deze variabiliteit en het gebrek aan onderzoek naar toxiciteit en tolerantie bij vee kunnen veilige gebruiksniveaus nog niet worden vastgesteld.

Summary Avocado production is rapidly expanding in Ethiopia due to rising global demand for avocado oil. However, cold-pressing, the most commonly used extraction method, generates over 90% waste, raising environmental concerns related to waste management. Given Ethiopia's shortage of affordable livestock feed ingredients, these by-products offer a promising local alternative. Their use, however, is limited by substantial variability in chemical composition, a high content of highly lignified fiber, and antinutritional factors such as tannins and persin, a compound linked to avocado toxicity in animals. This study shows that, in addition to chemical composition, persin concentrations are also highly variable. Due to this variability and the lack of toxicity and tolerance studies in livestock, safe inclusion levels cannot yet be established.

This report can be downloaded for free at https://doi.org/10.18174/694754 or at www.wur.nl/livestock-research (under Wageningen Livestock Research publications).

Public Wageningen Livestock Research Report 1580

Table of contents

Foreword

This report presents the results of a Seed Money Project (SMP24002) funded by the Topsector Agri&Food Consortium for Knowledge and Innovation (TKI A&F). Seed Money Projects support small and medium-sized enterprises (SMEs) in exploring opportunities for international collaboration. SMPs are initiated by consortia of companies active in innovative new developments in international collaboration. SMPs serve as a first step towards new initiatives, upon which follow-up activities can be formulated.

In this SMP, a consortium consisting of Koudijs Feed Company (part of De Heus Animal Nutrition), a selection of avocado processing companies in Ethiopia (SUNVADO, YBM, Soreti and Green Biz), Kenya, and the Netherlands (Soilmates), the Ethiopian Feed Manufacturers Association, the Ethiopian Horticulture Producers Association collaborated. The project was implemented and coordinated by Wageningen Livestock Research, with a private consultant from Ethiopia. Hiring a local private consultant was necessary due to the need for local data collection and sampling.

This project provides the first extensive examination of persin concentration, the most known antinutritional factor of avocado, in several avocado by-products. The project leads to interesting new insights into the potential of avocado processing by-products in livestock feed, opening the way for a more sustainable use of avocado waste in the animal feed industry.

A. Rezaei Far
M. Spoelstra
A. Alvarez Aranguiz

Summary

Avocado is a highly nutritious fruit with increasing global demand. Ethiopia, benefiting from favorable agroecological conditions, produced 168,000 tonnes of avocados in 2022 and is well-positioned as a key player in supplying high-quality fruit to international markets. However, the rapid expansion in avocado production is due to rising demand for avocado oil. Cold-pressing is the dominant oil extraction practice in Ethiopia, generates over 90% waste of the fruit's fresh weight in the form of wastewater, as well as peels, stones, and pulp known as avocado meal. These by-products, together with postharvest losses, are largely underutilized or discarded, contributing to environmental concerns. This highlights an urgent need for a sustainable waste management practice.

At the same time, Ethiopia, home to Africa's largest livestock population and a rapidly growing poultry sector, faces a critical shortage of affordable feed ingredients, threatening food security. Avocado by-products offer a promising locally available ingredients for feed. Industrial parks across Ethiopia produce substantial amounts of this waste. Despite this potential, there is limited research on the nutritional value and safe inclusion of these materials in livestock diets. Much uncertainty still exists about their application in feed, related to variabilities in the composition as well as the antinutritional factors.

The Circular Solutions for Avocado Waste in Ethiopian Animal Nutrition project addresses this dual challenge by evaluating the nutritional and antinutritional properties of avocado by-products and mapping their availability across the value chain. This initiative supports circular agriculture by transforming avocado waste into a sustainable feed resource while promoting food system resilience and innovation.

This project began with a literature review assessing the nutritional value and potential toxicity of avocado by-products for livestock. It then progressed to the fieldwork, analysing ten samples from commercial avocado oil extraction facilities. Based on the findings, the study concludes with recommendations for further research to support practical feed applications and outlines the business case for integrating avocado by-products as alternative feed ingredients within Ethiopia's livestock sector.

Literature study
A brief literature study indicated certain limitations for avocado by-products valorisation in feed, most importantly are as follows:

- Variations in the chemical composition, particularly residual fat and moisture
- High fiber content with a high lignification
- Presence of antinutritional factors such as tannin and persin

These factors complicated the practical application in feed formulation and may influence both the nutritional value and safety of avocado by-products when incorporated into livestock diets.

Persin is a bioactive fat-derivatives compound in avocado fruit, associated with avocado toxicity cases in animals. Toxicity studies conducted in mice used purified persin and indicated a toxic range of 60-100 mg/kg body weight, with higher levels resulting in mortality. However, no tolerance studies for avocado by-products in livestock species have been published. Only one published study has reported persin concentrations in commercial avocado meal, while a few studies assessed persin concentration in different parts of the fruit. Results suggest considerable variations depending on cultivar, fruit maturity, and climate conditions
The outcome of a few studies on the application of avocado by-products in livestock showed no adverse effects at inclusion levels up to 30% (fresh) or 10% (dried) avocado by-products. These outcomes may reflect species-specific tolerance to persin, degradation of persin during processing, or low persin concentrations in the tested materials. However, since persin content was not measured in those studies, conclusions regarding the safety of avocado by-products remain uncertain.

In light of these uncertainties, the present study aims to characterise the chemical composition and determine persin concentrations in ten samples of avocado by-products sourced from commercial oil extraction facilities. This preliminary step will inform future safety assessments and feed formulation strategies to valorise avocado waste in feed.

Results

The results indicate a substantial variability among the samples. Moisture content ranged from 8% to 19%, crude fat from 2%-37%, with a high fibre with lignification of 0.37-0.58, except in one sample with 0.06. Fat consisted mainly of unsaturated long-chain fatty acids. These variations significantly influence the nutritional value of avocado by-products for livestock and are likely attributed to differences in avocado cultivar, oil extraction practices (such as extraction method, inclusion or separation of peel and stone), and post-processing storage conditions (e.g. contamination with soil, microbial activity, and the varying proportion of peel and stone in the meal).

For the first time, Persin was quantified in multiple by-products of avocado oil extraction, showing higher levels in stone and peel than in avocado meal. Persin concentration in avocado meal ranged between 6-7945 mg/kg (as DM), while in the majority of samples it was below 1000 mg/kg (as DM). Given this wide range and the absence of persin toxicity or avocado by-products tolerance studies in livestock species, it is not currently possible to establish safe inclusion levels based solely on existing feeding trials. Further tolerance studies in target animal species are necessary to determine the safety of avocado by-products regarding persin content in feed. Additionally, research is needed to understand how processing methods influence persin concentration and bioactivity in avocado by-products

Conclusion

This study highlights the potential of avocado by-products as sustainable feed ingredients, particularly in the context of Ethiopia's growing need for alternative livestock feed sources. Avocado meal shows promise for ruminant diets, with a crude protein content comparable to wheat bran, while avocado stones could serve as an energy source for pigs and poultry, provided that persin and tannin levels are assessed and managed. In contrast, the high lignin content of avocado peel limits its nutritional value for livestock. Given the high initial moisture content of avocado meal (70–80%) and the associated wastewater from processing, these residues may also serve as suitable substrates for Black Soldier Fly larvae, though supplementation with higher-protein materials would be necessary to support optimal insect growth.

Despite the exploratory nature of this study, it offers valuable insights into the wide variability in the chemical composition of avocado by-products. To fully realize their potential in animal nutrition, further research is needed to assess digestibility, nutrient availability, and the impact of processing on antinutritional factors such as persin and tannins. Additionally, establishing safe inclusion rates through tolerance studies in target species is essential. Addressing these gaps will help transform avocado waste streams into cost-effective, safe, and nutritionally valuable feed ingredients, supporting circular agriculture and reducing environmental waste.

.

1 Introduction

Ethiopia is the country with the largest livestock population in Africa and with a poultry sector that has grown strongly over the past decade. Therefore, the demand for livestock commodities is rapidly increasing. The prices of feed ingredients and compound feeds have remarkably increased, while locally produced alternative ingredients can be incorporated into feed as a solution. However, technical solutions for using alternative feed ingredients are needed to cope with these changes.

Ethiopia's avocado industry is undergoing rapid growth, driven by modern agricultural practices and the introduction of improved avocado varieties aimed at enhancing smallholder farmers' livelihoods. This growth is supported by collaborative efforts from organizations such as USAID, Israel's MASHAV, and Ethiopia's Ministry of Agriculture. Together, they have introduced over 2,000 farmers to the profitable Hass avocado variety. As a result, exports, primarily to the Netherlands, have steadily increased year over year.

To further support the sector, modern nurseries have been established across regions like Tigray, Amhara, South, and Oromia, providing farmers with high-quality seedlings. A notable development is the Sunvado factory, located in the Yirgalem Integrated Agro Industries Park (IAIP), which produces premium organic avocado oil. This facility strengthens the supply chain while meeting international organic certification standards through an established monitoring system. In collaboration with Hawassa University, the factory is also advancing research and development to introduce improved avocado varieties.

Meanwhile, in the Jimma IAIP, Soreti International Trading PLC began producing avocado oil in November 2023. Similarly, GreenBZ Investment PLC has initiated operations in the Kilinto IAIP, focusing on avocado oil, medications, and cosmetics. Together, these ventures signify a concerted push towards modernization and value addition in Ethiopia's expanding avocado sector, offering economic upliftment and sustainable growth.

Ethiopia stands among Africa's top 10 largest exporting nations, rapidly emerging as a significant player in global avocado exports. Moreover, several countries are increasingly embracing avocados sourced from Ethiopia (Figure 1). However, this expansion brings with it a significant challenge: waste management in the avocado processing sector.

Avocado oil production, in particular, generates large volumes of organic waste, including the stone, skin, and pulp, collectively known as avocado meal. Managing this by-product is increasingly urgent. Studies estimated that up to 95% of the raw avocado fruit's weight is discarded during processing (GIZ, 2023). For example, a single commercial oil extraction unit processing 8,000 tonnes of avocados can produce nearly 7,660 tonnes of waste. Traditionally, this by-product has been underutilized, often ending up in landfills, causing environmental and potential health issues. As Ethiopia's avocado oil production continues to expand, the volume of organic by-products is expected to rise substantially, underscoring the need for sustainable waste management strategies.

This report is the outcome of a Seed Money Project carried out in Ethiopia in 2024. Seed Money Projects (SMP) are feasibility studies into potential innovations in the agricultural and livestock sector funded by the Topsector Agri&Food.

In Ethiopia, the SMP "Beyond Guacamole: Circular Solutions for Avocado Waste in Ethiopian Animal Nutrition" was carried out in 2024. The objective of this project was to evaluate the feasibility and profitability of using avocado by-products as a livestock feed ingredient in Ethiopia. This research aimed to provide evidence supporting the adoption of circular practices within the Ethiopian livestock industry, contributing to waste reduction, minimizing environmental pollution, and mitigating health hazards. Additionally, it seeks to offer innovative and cost-effective feed alternatives to address the challenges of a feed sector currently marked by high costs and limited availability. Consequently, this study holds the potential to enhance sustainability and efficiency in the animal production sector by promoting circularity.

Accordingly, Chapter 2 presents a literature review on the nutritional value of avocado by-products for livestock, along with an assessment of potential toxicity, particularly related to persin. Chapters 3 and 4 detail the fieldwork methodology and provide the results of chemical analyses conducted on samples collected from commercial avocado processing facilities. Chapter 5 offers recommendations for practical animal feed applications, while Chapter 6 outlines the business case for adopting avocado meal as an alternative feed resource.

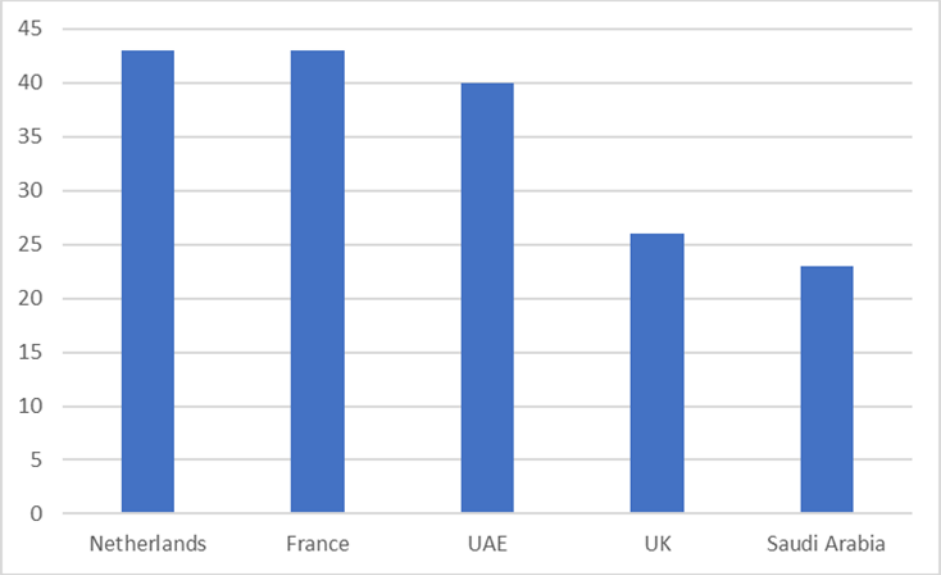


Figure 1 *Import volume of avocado from Ethiopia by country 2021 (Source: Freshela).*

2 Literature Study

2.1 The Ethiopian feed sector

2.1.1 Major feed ingredients

Feed processing plants in Ethiopia are operated by both private companies and farmers' unions, producing compound feed. While ingredients such as cereal grains and oilseed by-products, are domestically produced, feed premixes and additives are largely imported due to a lack of local manufacturing capacity.
Because cereal grains, such as maize and wheat, are primarily consumed by humans, livestock feed primarily relies on milling by-products such as wheat bran and maize bran. The most common ingredients in Ethiopian compound feed formulations include maize, sorghum, flour processing by-products (e.g., wheat bran, wheat shorts, rice bran), and various oilseed cakes used as protein sources. These include soybean meal, noug seed cake, linseed cake, groundnut cake, cottonseed cake, and sesame seed cake. Small amounts of molasses and feed additives, such as vitamins, minerals, and amino acids are also included. Premix categories are tailored for specific livestock types, including layers, broilers, and ruminants, and typically contain essential micronutrients and trace elements (Bediye et al., 2018).
Despite its potential and the unmet demand, Ethiopia's commercial feed sector faces multiple challenges. These include unstable supply and high prices of raw ingredients, concerns over feed safety and quality, limited access to feed analysis services, and difficulties in importing feed premixes due to foreign currency shortages.
The poultry sector is particularly reliant on commercial feed, with over 60% of poultry farmers depending on compound feed for production (Zegeye et al., 2023). However, many smallholder farmers continue to mix their own rations using locally available ingredients. Although the food and beverage industries (such as sugar, brewery, and agri-food processing) generate valuable by-products, these remain underutilized in feed production—representing an untapped opportunity for improvement.
A major concern in the feed supply chain is the growing gap between demand and supply. As shown in

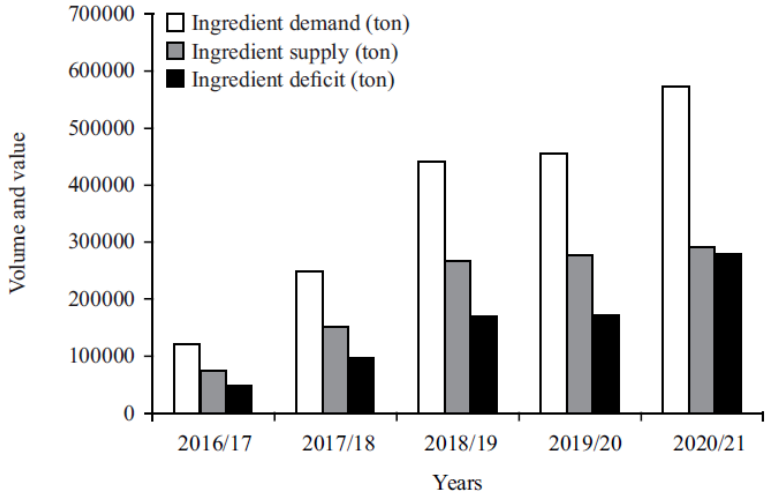


Figure 2 *Demand, supply and deficit of major feed ingredients (Noug seed cake, Ground nut cake, Soya bean cake, Linseed cake, Sunflower, Wheat bran, Wheat middling, Cotton Seed cake and Maize) (source: Demissie Negash, 2022).*

Figure 2, the demand for raw feed ingredients has been increasing more rapidly than the supply, contributing to underutilization of feed processing capacity. One contributing factor is the limited availability of wheat bran and other grain by-products, largely due to reduced wheat supply for flour production and the absence of locally cultivated maize in certain regions.

Regarding protein sources, trends in oilseed production have been mixed. Crops like soybean and groundnut have experienced growth in recent years, while sunflower and rapeseed production has declined—likely due to market shifts, profitability concerns, or agronomic challenges. If this trend continues, the limited availability of oilseeds could become a critical bottleneck for the feed industry (Yosef et al., 2022).
The study by Yosef et al. (2022) also indicated that by 2050, the country would need to expand 9% of arable land, increase cropping intensity by 14% and achieve a 77% increase in crop yield to meet the anticipated food and feed demand. These targets highlight the urgency of adopting more efficient and circular approaches within the agricultural and feed sectors.

Table 1 *Growth rate of production and sale of oilseeds from 2016/17 to 2020/21 (source: Demissie Negash, 2022).*

	Annual growth rate (%)									
	Production (2016/17-2017/18)	Market supply (2016/17-2018/19)	Production (2017/18-2018/19)	Market supply (2017/18-2018/19)	Production (2018/19-2019/20)	Market supply (2018/19-2019/20)	Production (2019/20-2020/21)	Market supply (2019/20-2020/21)	5 years growth rate	
Oilseed									Production	Market supply
Soya bean	9.32	10.45	68.30	67.44	-15.94	-16.37	66.11	66.11	156.80	156.9
Noug	6.90	4.60	-8.30	-9.50	-1.63	-2.82	-26.34	-26.35	-28.90	-32.23
Linseed	0.34	-15.40	11.28	24.45	-18.80	-7.74	0.95	0.95	-8.47	-1.94
Groundnut	11.98	14.17	-0.70	-1.34	8.60	7.98	30.96	31.00	58.15	59.35
Sunflower	20.40	-10.89	-15.90	-8.28	16.44	19.10	-54.28	-51.42	-46.10	-52.71
Sesame	-4.46	-12.15	-21.19	-16.18	30.24	38.03	-0.05	-0.23	-2.00	1.42
Rapeseed	-24.27	-36.76	16.27	16.37	10.02	10.11	-70.09	-70.09	-71.02	-75.76

2.1.2 Price trends in feed ingredients

The accessibility, quality, and rising costs of commercial compound feeds pose significant challenges to Ethiopia's feed and livestock industries, impacting consumers (Yosef et al., 2022, Demissie Negash, 2022). Compound feeds are essential for poultry, dairy, and beef production systems in Ethiopia, and they account for 70-80% of the total production costs.
The share of commercial feeds in the country's overall feed supply has steadily increased, driven by rising demand from expanding animal production sectors. However, most feed ingredients are by-products from food processing industries, and in the absence of clear regulatory frameworks or pricing guidelines, market transparency remains limited. In addition, the involvement of intermediaries in the market and the hoarding of feed by companies and farmers further contribute to the escalation of prices.
According to CSA (2021), data from the past five years show a persistent rise in the demand for feed, alongside increasing prices and recurring supply shortages. If not addressed urgently, this can become a crisis. Therefore, urgent and coordinated action is required from policymakers, development agencies, and private sector actors to formulate both immediate and long-term strategies to stabilize the feed market and support the livestock industry.

Highlights 2.1

- Ethiopia's commercial feed sector sources ingredients locally (cereal by-products and oilseed cakes), while relying heavily on imported feed additives and premixes. The sector faces multiple challenges, including high input costs, unstable ingredient supply, feed safety concerns, and limited access to quality testing services.
- Demand for feed ingredients is growing faster than supply, resulting in production deficits and underperformance across the feed industry.
- Besides the conventional ingredients, cereal and oilseed cake processing by-products, by-products from local agri-food industries (e.g. sugar, brewery, and fruit processing) are promising alternative feed ingredients. However, those remain underutilized contributing to waste management challenges and missed opportunities for circular resource use.
- Commercial compound feed prices in Ethiopia are rising due to growing demand, market inefficiencies, and lack of regulation, becoming a major risk to the livestock sector and food security. This requires an urgent multi-stakeholder intervention.

2.2 The Ethiopian avocado sector

2.2.1 Trends in the avocado sector

The avocado sector in Ethiopia holds significant potential but requires strategic investments for integrated and sustainable development. In recent years, both the area under cultivation and overall productivity have substantially grown (Table 2). Export volumes gradually increased until a sharp rise in 2018-2019, driven by growing global demand for avocados (Figure 3). However, the sector still faces several challenges that limit its ability to meet international and domestic market demands in terms of volume and quality (Jalata, 2021). Common challenges in fruit production in Ethiopia include the lack of a diverse genetic pool, limited understanding of fruit nutritional value, inadequate availability of improved planting materials and production techniques, insufficient postharvest technologies, issues with diseases and insect pests, and challenges in marketing (Derbew and Soon, 2015). Specifically for avocados, a study by Shamil Alo Sora (2023) found that improved cultivars such as Ettinger, Hass, Fuerte, Bacon, Nabal and Pinkerton yielded 84-370% more than local varieties indicating the need to shift towards high-yielding cultivars to meet growing demand.

Table 2 *Avocado sector evolution in Ethiopia (Source: CSA 2016 to 2021, FOA 2022).*

Year	Area (Ha)	Production (T)	Yield (T/ha)	H. Consumption (T)	Sale (T)
2016/17	17.835	65.982	3,6	34.700	28.540
2017/18	18.021	81.432	4,5	43.449	36.213
2018/19	19.759	84.794	4,3	45.789	37.309
2019/20	20.876	104.491	5,0	47.554	52.925
2020/21	30.588	245.335	8,0	111.849	121.196

Avocado cultivation is predominantly concentrated in the southern region of Ethiopia, particularly in Sidama, Wolayita, Jimma, Mizan Teferi, West Hararghe, and parts of Oromia, followed by Amhara and Benishangul-Gumuz (CSA, 2018). A recent review article by Kiere Abdela et al. (2023) outlined both advancements and persistent challenges in the sector. These include limited access to advanced technologies, poor transportation and storage infrastructure, weak market connections, and insufficient value addition efforts. While the sector has made promising growth and developments, overcoming these barriers is essential to fully unlocking Ethiopia's avocado potential for local livelihoods and global competitiveness.

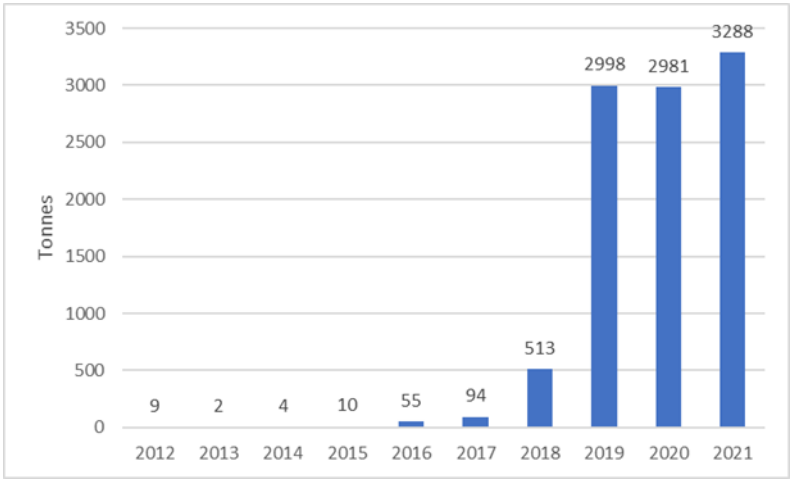


Figure 3 *The export volume of avocado from Ethiopia (Source: UN Comtrade, 2022).*

2.2.2 Avocado production

The avocado system in Ethiopia is intricately woven into the agroforestry practices of smallholder producers. In Sidama Highland in Southern Ethiopia, avocado trees are predominantly cultivated within the context of coffee, and to a lesser extent in conjunction with crops like maize. Avocado plays a dual role in agroforestry systems for coffee. Besides producing valuable fruits, avocado trees provide essential shade for coffee plants. Avocado is also commonly grown individually around courtyards, where it provides shade for people and livestock while contributing to farmers' income through the sale of its fruit.

Sidama, with suitable agro-ecological conditions for rainfed avocado production, contributes significantly to the national annual avocado production, accounting for approximately 36%, and is a major source of avocado fruits for prominent cities like Hawassa and Addis Ababa. This signifies the importance of avocado cultivation in these agroforestry systems, not only for local consumption but also for supplying urban markets, highlighting its economic significance for smallholder producers in Ethiopia (Biazin et al. 2018).

Ethiopia possesses favourable growth conditions conducive to the cultivation of various fruit trees, including avocados. However, the country has yet to fully capitalize on this potential. Avocado farming in Ethiopia faces challenges such as inadequate tree density per hectare and a lack of support from scientific agronomic practices. Cultivation often relies on unimproved seedlings, resulting in issues with fruit quality, shelf life, taste, and susceptibility to pests and diseases. Furthermore, the marketing of avocados is hampered by poor integration along the value chain. Despite opportunities like favorable soil conditions and inexpensive labor, oversupply leads to declining prices. The lack of improved post-harvest technologies and extension services further complicates production and marketing.

Challenges persist throughout the avocado value chain. Farmers struggle with obtaining disease-free seedlings, while limited storage facilities and a lack of collective bargaining power leave them vulnerable to unfavorable deals. Value addition occurs primarily at the farmer or wholesaler level, with unprocessed products dominating the market (Figure 4). Despite its potential for domestic and export markets, the avocado sector faces constraints due to inadequate post-harvest handling. A lack of organized institutions allows traders to control pricing, further inhibiting market development (Abduselam Faris, 2016).

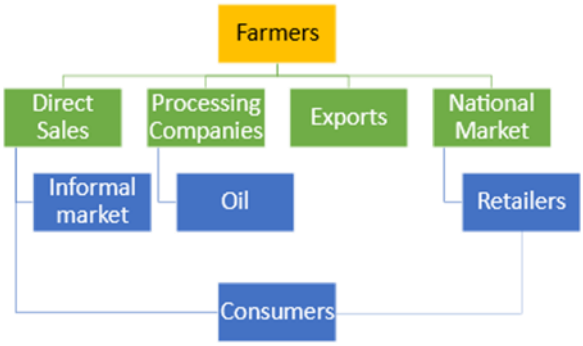


Figure 4 *Ethiopia avocado chain.*

Since 2018, there has been a notable increase in productivity in Sidama's rainfed avocado production, although challenges in good agricultural practices and post-harvest handling persist. Currently, 65% of the avocado harvest is sold to local markets, which still face unmet demands. There is a growing demand for affordable low-grade avocados, particularly for oil processing, with three processing facilities already established in Yirgalem and Hawassa, needing about 240 tons per day. Additionally, there is a significant push to export up to 60% of local avocado production, targeting markets in Djibouti, Somalia, and Sudan for ungraded products, and higher-grade markets in the UAE, UK, and the Netherlands, potentially reaching up to USD 325 million in export revenue.

Investment plans set in 2019 aim to drastically increase rainfed avocado production from 13,000 tons in 2019 to 221,000 tons by 2025.

Furthermore, these plans include increasing the portion of avocados marketed through formal channels from 68% to 77%, thereby enhancing the structure and profitability of the sector.

2.2.3 The effects of climate and season on avocado production

In Ethiopia, the seasonality of avocado production is clearly delineated, influenced by climate conditions and local agricultural practices. The growth and fruiting of avocado trees are greatly affected by temperature and rainfall, which dictate the timing of flowering, fruit development, and ultimately, harvesting. There are two main avocado harvesting seasons in Ethiopia. The first, from May to August, is marked by high production volumes aimed at supplying both local and international markets. This period coincides with a competitive

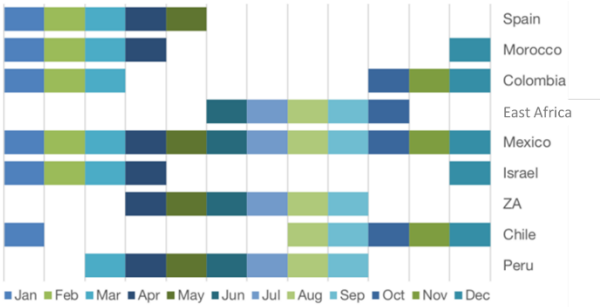


Figure 5 *Avocado Europe monthly supply calendar (Source: Eurostat, 2018).*

export niche for Ethiopia, as it fills a gap when the supply from major global producers, mainly in Latin America, is reduced (Figure 5). The second, shorter season spans from September to October and typically yields a smaller harvest.

Avocado harvest timings can vary depending on the variety, but typically, farmers aim to pick the fruit at peak ripeness. Harvesting may continue into the rainy season in some regions, influencing the overall yield and quality of the crop. Although avocados are somewhat resilient to low rainfall, the lack of water can affect the size, shape, and quality of the fruit. Most small-scale avocado farmers in Ethiopia do not have access to irrigation and rely on natural rainfall, making them susceptible to fluctuations in weather conditions. In contrast, a few large-scale commercial farms equipped with irrigation systems can maintain consistent production quality throughout these seasons.

The main avocado-producing regions in Ethiopia include Sidama, Wolyaita, Jimma, Mizan Teferi, West Hararghe, and Oromia. The country has a sub-tropical climate in the southern areas, thanks to its proximity to the equator. This climate is characterized by high humidity, abundant rainfall, temperatures ranging from 20°C to 30°C, and at least 6 hours of sunshine per day. Avocado trees thrive at altitudes between 1,500 and 2,100 meters above sea level, where they benefit from well-distributed rainfall of 1,000 to 1,600 millimeters throughout the year. Seasonality plays a significant role in logistics and plant processing, leading to variations in waste generation.

Climate variability, along with outbreaks of pests and diseases, negatively impacts the quality of avocados, ultimately reducing their export potential. According to Humble and Reneby (2014), the largest losses of avocados in Ethiopia occur at the following stages:

- Harvest: Primarily due to poor harvesting techniques.
- Transport: Mainly caused by improper loading and unloading.
- Storage: Largely a result of over-ripening.

Highlights 2.2

- Despite growth in avocado production, Ethiopia still falls short of meeting domestic demand and the need for low-grade avocados for oil extraction. Investment plans aim to raise production to 221,000 tons by 2025.
- Ethiopia's growing avocado sector holds strong potential but faces key challenges, such as low-yielding local varieties, poor infrastructure, and limited market access, resulting in fruit losses during harvest,

Highlights 2.2

transport, and storage. In addition, climate change impacts on rainfall and pests reduce avocado production and quality, while seasonality restricts logistics and plant processing.

- Strategic investment and modernization are necessary to meet rising domestic and global demand.

2.3 Avocado by-products

2.3.1 Composition of avocado by-products

Avocado processing generates significant by-products, including peels, stones, pulp residues, and wastewater, which are often discarded despite their nutrient and valorisation potential. These residues contain high levels of fiber, as well as lipids and bioactive compounds with antioxidant, antimicrobial, and metabolic properties, making them promise for livestock feed and other bio-based applications.

The avocado supply chain involves multiple stages—cultivation, harvesting, sorting, cooling, washing, packing, and temporary storage—each contributing to biomass generation. Industrial processes for oil and guacamole production are major sources of by-products. Globally, about 40% of the avocado fruit is discarded as by-products, amounting to roughly 1.6 million tons annually. In Ethiopia, cold-press oil extraction using local varieties yields only 4–5% oil, producing by-products comprising 23–25% peel and stone, and 72% pomace.

Avocado oil extraction methods influence the composition and volume of by-products. Solvent extraction (e.g. using hexane) produces higher oil yields (up to 95%) but compromises the organoleptic quality of avocado oil. In contrast, cold-pressing is preferred for extra virgin oil production preserving the organoleptic properties but generating larger volumes of by-products. For instance, For instance, processing 1,000 kg of fruit by cold-pressing yields 4–6% oil, 700–800 kg of pomace, and 230–270 kg of peel and stone. Another mass balance study reports by-product yields of 44.8% wastewater, 27.4% peel and stone, 15% pomace, and 5% residual water, with only 7.8–8.5% of fruit mass recovered as oil (Permal et al., 2020).

Beyond oil, avocado processing for guacamole, juices, and dried products also produces considerable waste. For example, guacamole production results in peels, stones, and pulp, which can be valorized directly as livestock feed or converted into high-protein and high-fat biomass using black soldier fly larvae.

2.3.2 Nutritional characteristics of avocado by-products

Avocado by-products show considerable nutritional potential, while their high moisture content and variability in composition limit their storage and further application. Fresh avocado meal contains about 80% moisture, which can be reduced to around 5% through drying reducing the activity of heat-labile antinutritional factors as well. However, drying is energy-intensive and, if not properly controlled, may degrade nutrient quality, particularly protein.

Moisture levels vary widely among different by-product components: the pulp can contain up to 83% moisture, while the stones contain less moisture around 57% (Table 3). This variability complicates storage and processing. Furthermore, the composition of the avocado meal depends on the ratio of peel, pulp, and stone, which varies with the extraction method used.

Nutrient analysis indicates that avocado meal from commercial oil production typically contains 12–16% crude protein, around 10% ether extract, and at least 30% fiber. For example, peel meal from Mexico has been reported to contain 7% crude protein, 16% ether extract, 43% neutral detergent fiber (NDF), and 28% non-fiber carbohydrates on a dry matter basis (Mendez Zamora et al., 2024).

Lipid content in avocado by-products is modest but valuable. A study using the Folch method on 'Hass' avocados in Portugal found lipid contents of 5.0% in the peel and 4.8% in the stone (Neves et al., 2025), consisting primarily of unsaturated fatty acids like oleic acid. These lipids are desirable for both feed and bio-based product applications, though variability across cultivars and processing conditions remains a challenge.

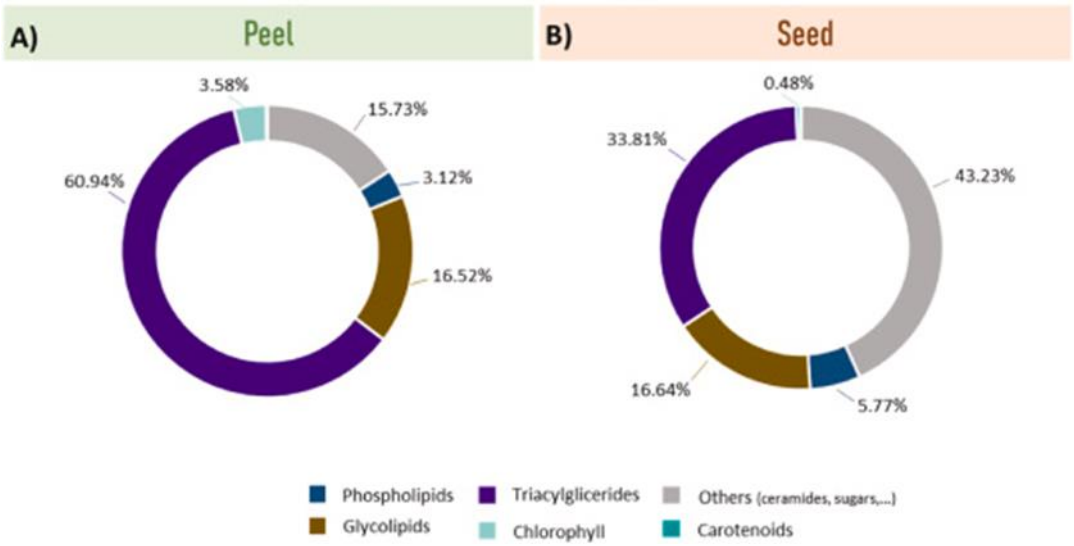
Overall, while avocado by-products are currently underutilized, their nutritional profile and bioactive properties present clear opportunities for circular applications—especially in animal nutrition—if technical and processing barriers are addressed.

Table 3 *Summary of avocado by-products nutritional composition in % as fresh weight (various sources).*

By-Product	Moisture	Ash	Lipids	CP	NDF	Carbohydrates	Lignin
Pulp	81-83	5-7	9	15-13	NA	NA	26
Peel	70-75	1-9	6-10	6-9	40-60	43-81	26-35
Stone	32-57	1-3	2-6	4-5	30-40	42-81	14-16

2.3.2.1 Avocado stone:

Avocado stones also referred to as seeds, endocarps, or pits, represent 13-18% of the waste generated from cold-pressed avocado oil production. Despite their potential as a feed ingredient, caution is necessary due to the presence of antinutritional compounds such as persin and tannins. Studies highlighted the nutritional composition of avocado stones, with Uchenna et al. (2017) reporting moisture content (8.5%), crude protein (9.6%), lipids (1.4%), and ash (4.9%). Additionally, the total carbohydrate content in avocado stones from Malaysia was found to be 74%, with 66% starch (Reviewed by Tesfaye et al., 2022). The high starch content, positions avocado stones as a promising alternative starch source to replace cereals in animal feed, potentially improving production parameters such as body weight gain and feed efficiency.



However, the presence of antinutritional factors, including oxalates (4.4%, 15 mg/100 g), tannins (0.24–

Figure 6 *Lipid composition of peel and stone in five samples of Hass cultivar (Neves et al., 2025).*

1.4%, 7 mg/100 g), alkaloids (0.7–5%), phytates (0.44%), flavonoids (0.1–20%), phytic acid (3 mg/100 g), and saponins (0.5–19%) (Cheikhyoussef & Cheikhyoussef, 2022), limits their direct use in feed. These compounds can interfere with nutrient absorption and animal health, necessitating moderation and potential processing to mitigate their effects. While avocado stones offer a valuable source of calories and carbohydrates, their integration into animal feed must be carefully managed to balance nutritional benefits with the risks posed by antinutritional substances.

2.3.2.2 Avocado peel (skin, or epicarp/exocarp)

Avocado peel contains proteins (4–8%), lipids (4–9%), and carbohydrates (62–73%), primarily in the form of fiber (Akan, 2021). While the total lipid content is reported between 4% and 9% on a dry matter basis, ether extract values as high as 43.7% (Negesse et al., 2009) and 58.9% (Navarro Marcos et al., 2020) have been observed. These high ether extract values likely include not only true lipids but also non-lipid compounds such as waxes and pigments.

The reported high fat content corresponds to a gross energy value of 7,290 kcal/kg (Navarro Marcos et al., 2020), though the metabolizable energy is significantly lower at 3,250 kcal/kg (Negesse et al., 2009). The discrepancy in energy content can be attributed to the high lignin content of avocado peel (12.5% DM), which reduces digestibility compared to other fruit peels, such as banana (0.6–4.7% lignin DM) (Negesse et al., 2019). The lower organic matter digestibility (37%) supports the impacts of the high lignin content on energy availability compared to peels from mango, papaya, pineapple, banana, and orange, which have digestibility values exceeding 70% (Negesse et al., 2019).

The high fat content can also reduce the digestibility of avocado peels, since it suppresses bacterial degradation in the rumen. Despite these observations, inconsistencies exist in reported fat content. For instance, a commercial avocado peel meal sample contained 15.5% crude fat (Mendez-Zamora et al., 2024), while the total lipid content has been reported between 2–9% DM (Neves et al., 2024). These variations may stem from differences in cultivars, residual pulp presence, and fat extraction methods, suggesting that ether extract values might include non-lipid components. In addition, the contribution of microbial activities to the fat content of avocado peel cannot be ruled out when fatty acids with odd carbon chain length have been observed. Therefore, methodological differences should be considered when comparing studies, and further research is needed to clarify the true lipid content of avocado peel and its digestibility.

In addition to its macronutrient profile, avocado peel is a rich source of bioactive compounds, including phenolic compounds, flavonoids, and tannins, which exhibit strong antioxidant properties. The total phenolic content (TPC) in avocado peel varies widely, ranging from 0.6 to 6.8 mg gallic acid equivalent (GAE)/g in fresh peel and 4.3-120.3 mg GAE/g in dried peel, depending on the cultivar. Ripe Hass avocado peel, for instance, has shown the highest TPC at 77.9 mg GAE/g and total tannin content (TTC) at 149.0 mg catechin equivalent (CE)/g. Unripe Hass avocado peel, on the other hand, contains 3.44 mg quercetin equivalent (QE)/g of total flavonoids (Velderrain et al., 2021; Akan et al., 2021; Lyu et al., 2023). These bioactive compounds may interfere with microbial activity in the rumen as well.

Comparative studies have further highlighted the bioactive potential of avocado peel. For example, the total tannin content in avocado peel from Ethiopia was measured at 39.0 g/kg DM, with condensed tannins at 22.1 g/kg DM (Negesse et al., 2009). While this is comparable to orange peel (28 g/kg DM), it is significantly lower than mango peel (130 g/kg DM). Similarly, the total phenolic content in avocado peel (49 g/kg DM) is on par with orange peel (51 g/kg DM) but about three times lower than that of mango peel. These findings underscore the variability in bioactive compound concentrations across different fruit peels and highlight the potential of avocado peel as a source of natural antioxidants and functional ingredients.

2.3.2.3 Avocado wastewater (AWW)

Avocado wastewater (AWW) is the most significant by-product of cold-pressed avocado oil production, representing approximately 500 kg for every 1,000 kg of processed fruit, compared to 80 kg of oil yield. With its high moisture content (88%) and nutrient-rich dry matter composition—10% protein, 54% fat, 18% ash, and 22% dietary fiber (Permal et al., 2020)—AWW presents both a disposal challenge and a valuable resource for alternative applications.

One promising approach is the spray drying of AWW into a powdered form, which enhances its functional properties. The process, conducted at temperatures between 110°C and 160°C, significantly increases the total phenolic content (TPC) and antioxidant capacity of the resulting powder. This valorized product exhibits 20 times greater antioxidant activity, and 8 times higher phenolic content compared to avocado pulp, making it an effective natural preservative. For instance, the powder has demonstrated success in preventing lipid oxidation in pork sausages (Permal et al., 2020), highlighting its potential as a functional ingredient in the food industry. This method not only addresses the issue of AWW disposal but also aligns with circular economy principles by transforming waste into a high-value product.

However, the spray drying process can be costly, prompting exploration of alternative uses for AWW. One such application is its use as a moisture source in substrates for rearing Black Soldier Fly larvae (BSFL). BSFL thrive in substrates with 70-80% moisture, and AWW's high moisture content makes it an ideal candidate for this purpose. Utilizing AWW in BSFL rearing not only provides a sustainable waste management solution but also contributes to the production of protein-rich insect biomass for animal feed. While this approach shows promise (Popa & Green, 2012), further research is needed to optimize the integration of AWW into BSFL rearing.

2.3.3 Antinutritional compounds and phenolic compounds

Avocado processing, particularly cold-press oil extraction, generates a huge number of by-products. Incorporating the by-products in livestock feed can be a feasible and sustainable solution for waste management, but also providing alternative ingredients in challenging ingredient markets. The chemical composition of these by-products was discussed above; however, these by-products contain anti-nutritional factors which can limit their inclusion level in feed. Besides tannins and other phenolic compounds which are known as antinutritional factors in feed, avocado by-products contain persin which has been associated with avocado toxicity cases in animals.

2.3.3.1 Persin

Persin ($C_{23}H_{40}O_4$) is a fat-soluble natural compound found in avocado fruit and leaves, produced by idioblasts, the oil cells in the plant. It belongs to a group of bioactive molecules known as acetogenins, which are long-chain unsaturated fatty acids derived from fatty acid biosynthesis. Acetogenins exhibit antimicrobial, antifungal, and insecticidal activities, making them significant in plant defence mechanisms. Due to its structural similarity to linoleic acid monoglyceride, persin has gained attention for its biological activities, including cytotoxicity and antimicrobial properties.

The distribution of persin varies among different parts of the avocado plant. Typically, the highest persin concentrations are found in avocado leaves, followed by stones, and then pulp. However, cultivar-specific studies show variability in this pattern. For instance, Rodríguez-López et al. (2015) reported that, in certain avocado cultivars, pulp contained higher persin levels compared to stones and peel.
This observation contrasts with the general understanding, where stones and peel are considered to contain more persin than pulp. These differences underscore the importance of cultivar effects when assessing persin distribution within avocado plant parts. It seems that persin is well-tolerated by humans, but avocado toxicity has been reported in various animals such as sheep (Grant et al., 1988), goats (Craigmill et al., 1989), dogs (Buoro et al., 1994), rabbits (Aguirre et al., 2019), and ostriches (Burger et al., 1994) and has been associated with the cytotoxicity of persin with symptoms including mastitis and myocardial necrosis. When lactating livestock consume avocado leaves, they may develop non-infectious mastitis. Studies have shown that persin, when administered at 100 mg/kg body weight (BW) in rats, causes specific lesions in mammary glands. However, research also suggests that persin may have potential benefits, such as inhibiting the growth of certain breast cancer cells (Butt et al., 2006; Oelrichs et al., 1995).

Table 4 *Persin levels in avocado leaves and different fruit parts from literature.*

Method	Origin	Sample	Concentration	Citaiton
LCMS	USA	Freeze-dried Peel	0.7 mg/g	Dainton et al., 2022
		Freeze-dried Pulp	0.1 mg/g	
		Freeze-dried Stone	0.1 mg/g	
		Meal	<0.01 mg/g	
		Fresh pulp	0.02-0.5 mg/g DW	Rodríguez-López et al., 2015
LC-MS	New Zealand	Oven-dried stone	1.7 mg/g DW	Permal et al. 2023
		Freeze-dried stone	1.8 mg/g DW	
		Extruded stone	0.7 mg/g DW	
HPLC-PDA/ELSD		Leaves	2.6 mg/g fresh weight (7.5 mg/g DW)	Rodríguez-Sánchez et al., 2019
		Stone	1.3 mg/g fresh weight (3.2 mg/g DW)	
		Pulp	1.6 mg/g fresh weight (6.4 mg/g DW)	

A few studies assessed differences in persin concentration within avocado plant parts and among cultivars (Table 4). For instance, the persin concentration in avocado peel (0.72 mg/g) was significantly higher than in the pulp (0.11 mg/g) and stone (0.10 mg/g) (Dainton et al., 2022). Among 21 avocado cultivars, persin concentration ranged between 0.1-0.9 mg/g in peel, 0.0-0.3 mg/g in stones, and 0.05-1.3 mg/g in pulp (as fresh weight) (Rodríguez-López et al., 2015). Interestingly, despite this variation pulp contained higher persin levels compared to stones and peel across cultivars (Rodríguez-López et al., 2015) which contrasts with the general understanding of peel and stone as the main source of persin than pulp. Additionally, leaves from 21 different avocado cultivars showed persin concentration between 0.4 to 4.5 mg/g (as fresh weight) (Carman & Handley, 1999) which indicated a notable cultivar-specific variations and higher leaf persin content compared to fruit. Therefore, persin levels are higher in avocado leaves compared to avocado fruit, while the cultivar is an important source of variations for the persin content, explaining the reason for the number of reports on toxicity by consuming avocado leaves.

The application of avocado processing by-products in feed is focused on fruit, particularly the Hass cultivar. Assessing persin concentration in Hass cultivar stones and pulp were 1.3 and 1.6 mg/g (as fresh weight), respectively (Rodríguez-Sánchez et al., 2019) which is comparable to previous results reporting persin concentrations in pulp around 1.5 mg/g (as fresh weight) (Kobiler et al., 1993). Nevertheless, substantial variation exists, with some studies reporting lower persin levels in pulp such as 0.36 mg/g fresh weight (Degenhardt & Hofmann et al 2010) and 0.1 mg/g in freeze-dried pulp (Dainton et al., 2022). Notably, higher persin levels were observed in avocado stone which was 1.8 mg/g in freeze-dried samples (Permal et al. 2023), However, we found only one published result on persin concentration in a dried avocado meal sample from a commercial avocado processing unit in the USA which was lower than the detection limit of the test (<0.01 mg/g) (Dainton et al., 2022). Avocado meal from commercial oil extraction units has different proportions of partially defatted pulp, stone, and peel. Given the higher persin concentration of stone and peel compared to pulp, we can assume that the presence of these fruit parts in avocado meal is an important source of variations in persin levels.

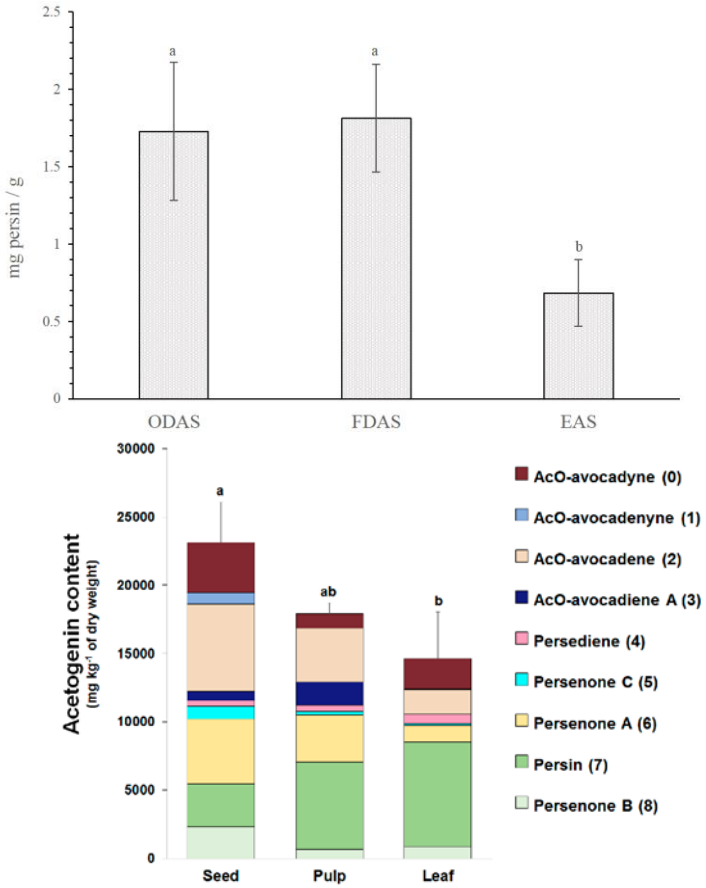
The toxicity of persin depends on its concentration in the feed and the uptake dosage. Only the R enantiomer of persin is biologically active, with toxic effects occurring at 60-100 mg/kg BW. In doses exceeding 100 mg/kg BW, persin can damage tissues such as the heart muscles. For example, purified persin administered to lactating mice at 60-100 mg/kg resulted in mastitis, while doses greater than 100 mg/kg led to myocardial necrosis (Oelrichs et al., 1995). In goats, 20 g of avocado leaves per kg BW caused severe

Figure 7 - Acetogenins profile of avocado fruit parts and leaves in 3-5 samples from Hass cultivar in Mexico (Rodriguez-Sanchez et al., 2019)

mastitis, while 30 g/kg resulted in cardiac injury. Similar toxic effects, including acute cardiac failure and myocardial necrosis, have been reported in sheep, horses, and birds consuming avocado leaves and fruit.

While persin is the most studied acetogenins in the avocado, other acetogenins also show bioactive properties and even can be the major acetogenins compared to persin. In the Hass cultivar, the primary acetogenins in the pulp and peel were persenone A and persin. In contrast, persin constituted only a minor portion of the total acetogenins present in stones (Rodríguez-López et al., 2015). In another study, the main acetogenin of the pulp was persin (43%) followed by Persenone A (20%) and avocadyne (17%). In contrast, in the stone of the Hass cultivar the main acetogenins were avocadene (27%), avocadyne (23%), followed by persenone A (18%) and persin (14%). Persenone A and AcO-avocadene showed antimicrobial activity against food pathogens such as Clostridium (Pacheco et al., 2017). Figure 7 provides an overview of different acetogenins in stones and pulp compared to leaves. Interestingly, while persin concentration is highest in leaves, total acetogenin content is lower in leaves than in stones or pulp (Rodriguez-Sanchez et al., 2019). In both studies, pulp of Hass cultivar had a higher persin concentration compared to stones, while the total acetogenin concentration was higher in stones than in pulp (Rodriguez-Sanchez et al., 2019; Rodríguez-López et al., 2015). This outcome can be different in other cultivars. Further research is necessary to understand the mode of action, and the optimum concentration, as well as the safety of persin and other acetogenins in avocado by-products for different livestock species.

Understanding the factors that influence persin concentration is essential for optimizing its safe use in food and feed applications. The results of studies on persin concentration are mainly unrelated to its toxicity or application in feed. The exception is the study of Dainton et al. (2022) which assessed the concentration in commercial avocado meal.



The potential use of avocado by-products in livestock feed requires further investigation, as the concentration of persin and other acetogenins differs among cultivars and environmental conditions (Freitas et al., 2022). Also, the rise in avocado weight during maturation is highly correlated with the rise in lipid content, since lipid is mainly biosynthesized at this stage. However, this is negatively correlated with the total persin content of the fruit since persin concentration remains constant (Rodriguez-Lopez et al., 2017). Thus, persin concentration (as fresh weight) reduced as avocado fruit matured. Research has shown that persin content decreases with ripening due to increased lipoxygenase activity, which degrades the compound (Rodriguez-Lopez et al., 2017).

Climate condition affects persin concentration in avocado pulp and stones, since persin concentration was higher in a dry year compared to other years (Rodriguez-Lopez et al., 2017). Therefore, in addition to cultivars, factors such as fruit maturation, post-harvest ripening, and climate conditions can influence persin levels of the fruit and by-products.

In addition to the persin concentration of fruit, processing methods affect persin levels of avocado processing by-products. Dainton et al., (2022) suggested that the exposure of persin to heat and light during processing may oxidize this fat compound. According to figure (8), extruding avocado stones at 130°C reduced persin levels compared to oven drying (at 70ºC) or freeze-drying (Permal et al., 2022). However, the researchers executed a thermostability test showing that extracted persin was stable at 130°C suggesting other reasons such as the reaction of persin with other compounds during extrusion causing declined persin levels in the extruded avocado stone (Permal et al., 2022). Despite its potential toxicity, avocado meal has been used in animal diets without observing health conditions. In one study, the incorporation of 18% dried avocado meal in the diet of dogs was not associated with health issues (Dainton et al., 2022) suggesting that processing methods can mitigate persin toxicity, making avocado by-products potentially safe for consumption.

In conclusion, little is known about persin concentration in avocado processing by-products. Only a limited number of studies assessed the concentration of persin in a few samples from fresh avocado fruit, while the toxicity studies have been executed with purified persin samples. What is not yet clear is the impact of oil extraction and drying on persin concentration and functionality in avocado meal. In addition, the toxic dose of persin in different livestock species has not been yet established.

2.3.3.2 Phenolic compounds and tannins

Besides persin, tannins in avocado by-products act as an antinutritional factor. Tannins are phenolic compounds. They can bind to nutrients such as protein and minerals reducing their absorption in feed. Also, tannins inhibit digestive enzyme activity and in high concentration can irritate the gastrointestinal tract. Besides that, tannins are associated with a bitter taste in ingredients reducing feed palatability. The amount of tannins added to the ration should be at a level that will not have a toxic effect on animals.

Tannins content in avocado by-products can vary depending on several factors such as the avocado cultivar, the maturity of the fruit, and the specific fruit parts present in the by-products mix. Although avocado fruit is not considered a major source of tannins compared to fruits such as grapes, berries, and pomegranates, the stones and peels of avocados contain higher concentrations of tannins compared to the pulp.

Figure 8 -Persin concentration in oven dried (70°C, 60 hours) avocado stone (ODAS), freeze-dried avocado stone (FDAS) and extruded avocado stone (EAS), based on dry weight (DW) (Source: Rahul Permal, 2022).

Research studies have reported varying levels of tannins content in avocado stones and peels. For example, one study found that avocado stones contain tannins concentrations ranging from 0.07% to 0.25% (as DM) (Salazar-López et al., 2020). In another study, tannins content of avocado stones was 0.45% (Runyogote et al., 2021). Another study reported tannins content in avocado peel extracts to be around 0.57% and 3.9% as DM (García-Vargas et al., 2020). The total condensed tannins in a mixture of pulp and peel were 2.3% as DM (de Evan et al., 2020). In contrast, the concentration of condensed tannins in commercial avocado meal samples from South Africa was 14.3% as DM (Skenjana et al., 2006).

In avocado peel and stones, the majority of total phenol (~80%) is tannins (Negesse et al., 2009; Figueroa et al., 2018). However, those contain other phenolic compounds as well. While phenolic compounds are known generally as antinutritional factors for poultry reducing feed palatability, and nutrient and minerals digestibility, they also have antioxidant effects. Despite oven-drying or extruding, avocado stones maintained the antioxidant capacity associated with total phenolics content of 16.9 and 12.9 (mg/g equivalent Gallic acid), respectively (Permal et al., 2023). While the antioxidant activities of the phenolic compounds can be interesting in increasing the resilience and health of livestock, the negative effects on palatability and the nutrient digestibility of the final feed need to be assessed.

2.3.3.3 Other bioactive compounds

Avocado by-products also contain a variety of other bioactive compounds with functional properties, including antioxidant, antimicrobial, and anti-inflammatory activities (Jimenez et al., 2020; Bhuyan et al., 2019). Carotenoids, particularly xanthophylls and carotenes, are present in the pulp and contribute to the yellow pigmentation in egg yolks and broiler skin when included in poultry diets. These compounds also offer health-promoting effects as vitamin A precursors, immune enhancers, and antioxidants.

Moreover, avocado pulp has been found to contain antimicrobial peptides such as defensins, which show activity against common pathogens including Escherichia coli and Staphylococcus aureus (Guzman-Rodriguez et al., 2013).

However, processing methods, especially drying at high temperatures, can negatively affect the stability and activity of these bioactive compounds, particularly peptides and polyphenols. This underscores the potential benefit of using minimally processed avocado by-products to preserve their functional properties when incorporated into livestock feed.

Highlights 2.3

2.3.1

- Avocado processing generates large volumes of by-products (peels, stones, pomace, and wastewater), which are often discarded despite their valuable nutritional and bioactive content.
- Cold-press oil extraction, the dominant method in Ethiopia, yields high-quality oil but produces over 90% waste by weight, highlighting the need for effective waste valorization.
- Avocado by-products are rich in fiber and unsaturated fats with moderate levels of crude protein making them promising candidates for livestock feed and bio-based products, if properly processed.
- High moisture content and compositional variability present major challenges for storage, processing, and further application, requiring controlled drying and standardization.

2.3.2

- Avocado wastewater, the largest by-product of cold-pressed oil production (~50% fresh fruit weight), shows promising potential for valorization, such as an antioxidant-rich powder for food preservation via spray drying or as a moisture source in Black Soldier Fly larvae substrates. Both applications require further research to assess feasibility and scalability.
- Avocado stones account for about 20% of the waste from cold-pressed oil production and are rich in starch (66%), offering potential as a cereal substitute in animal feed. However, antinutritional compounds such as persin, tannins, and oxalates can limit their inclusion levels unless properly processed.
- Avocado peels are high in fiber and fat, with considerable gross energy content, while the high lignin content limits the available energy content. It has antioxidant potential due to phenolics content.
- The high lignin content of avocado peel limits its use in monogastric diets. Both lignin and its relatively high fat content, mainly unsaturated fatty acids, can reduce avocado peel degradability in ruminants.

2.3.3

- Persin is a fat-soluble acetogenin produced in avocado leaves and fruit exhibits cytotoxicity (e.g., mastitis, myocardial necrosis). The toxic effects of pure persin are seen in mice at 60–100 mg/kg body weight.
- Persin concentrations are generally highest in leaves (up to 4.5 mg/g), followed by peel and stone, with the lowest in pulp. Although studies on the Hass cultivar report higher persin levels in pulp than in other fruit parts, showing cultivar-dependent patterns. Its levels vary by plant and fruit part, cultivar, fruit maturity, and climate condition
- Persin content in avocado by-products is highly variable, and limited data exist on its levels in processed forms like avocado mea. Most notably, one commercial meal sample showed persin levels below detection limits (<0.01 mg/g), suggesting processing methods can reduce persin levels. Potentially exposure to heat or chemical interactions degrade persin, making by-products safer for use in animal feed.
- Other acetogenins in avocado, such as persenone A, avocadene, and avocadyne, also exhibit bioactivity and may be more abundant than persin in certain fruit parts, particularly stones.
- The safety and nutritional viability of avocado by-products in livestock diets depend on persin content, while the tolerance of different livestock species and effects on product quality have not been clear yet highlighting the need for further research.
- Avocado by-products, particularly the peel and stone, contain tannins and other phenolic compounds with both antinutritional and antioxidant properties. Their effects on feed palatability and nutrient digestibility require careful evaluation.
- In addition to tannins, avocado by-products provide bioactive compounds such as carotenoids and antimicrobial peptides, which may support animal health, though their activity can be reduced by high-temperature processing.

2.4 Potential uses of avocado residues in animal feed

Avocado residues, such as meal, stones, and peels, can be utilized in various ways, including animal feed and other industries. The high fibre content of the avocado meal, a by-product of cold-pressed avocado oil extraction, suggested its application in animal feed, primarily for ruminants. The high lignin content of avocado peel limits its application in monogastric diets, while avocado stones can be processed into milled and applied as a source of starch for monogastric. Besides the macronutrients, avocado by-products contain antioxidants, fats, and vitamins, which can be harnessed to improve animal feed and other products, reducing waste and promoting sustainable practices. So far, the application of different avocado residues in feed has been investigated in a few studies which are addressed in this section (Table 6).

Table 5 *An overview of the chemical composition (% as DM) of different avocado prodcuts studied in animal feed.*

	Region	Moisture	Ether Extract	Crude Protein1	Crude Fiber2	Ash	Citation
Dried meal[a]	US	5.9	9.1	11.5	37.4	9.0	Dainton et al., 2022
Dried meal[a]	South Africa	5.1	6.3	15.6	34.9	NA	van Ryssen et al. 2013
Fresh meal[b]	Israel	81.4	18.2	14.7	NDF 65.2 ADL 26.9	4.5	Eliyahu et al., 2015
Stone [c]	Indonesia	11.8	7.3	5.8	3.1	2.7	Tugiyanti et al., 2019
Stone [d]	Mexico	2.8	19.4	4.6	69.2	2.3	Velázquez-González, et al.2023
Stone[e]	Mexico	4.0	4.6	4.9	6.7	2.3	Pahua-Ramos et al., 2012
Dried ston[e]	Spain	11.0	4.2	8.8	ADF 10.8	5.8	Haro et al., 2022
Pulp:peel mixture	Spain	75.3	64.0	7.2	NDF 9.0 ADF 6.3 ADL 0.4	NA	De Evan et al. 2020
Pulp:peel mixture	Spain	75.6	63.8	10	NDF 8.9 ADF 6.3 ADL 0.4	NA	Navarro Marcos et al., 2020
Pulp	Mexico	77.3	NA	7.7	NA	3.5	Ly et al., 2021
Stone		57.1	NA	5.5	NA	1.3	
Peel		77.3	NA	7.3	NA	3.4	
Fresh pulp	Mexico	74.1	63.2	8.1	NA	NA	Grageola et al., 2010
Fresh whole fruit	Mexico	NA	49.1	9.2	14.3	NA	Grageola et al., 2019
Fresh whole paste	Mexico	68.0	49.1	9.2	14.3	3.3	Franquez et al., 2017
Meal silage	South Africa	62.1	13.5	35.9	ADF 39.1 ADL 19.9	6.5	Seshoka et al., 2020
Sun-dried peel	Ethiopia	75.2	43.7	7.1	NDF 26.1 ADF 23.3 ADL 12.5	8.7	Negesse et al., 2009
Peel	Mexico	NA	15.5	7.0	12.1 NDF 42.9	7.6	Mendez-Zamora er al., 2024
Peel	Spain	76.4	58.9	10.0	NDF 11.5 ADF 10.4 ADL 3.5	NA	Navarro Marcos et al., 2020

a Commercial dried avocado meal
b Commercial dried avocado meal
c stones were soaked in water overnight before being sundried
d freeze-dried
e Oven dried
1)Nitrogen X 6.25
2)Crude fibre unless else is mentioned.

2.4.1 Ruminants

The waste products from avocado processing industries present a promising alternative as feed ingredients for livestock. Incorporating these by-products into animal feed can address waste management challenges while offering a cost-effective feed solution. Due to their high dietary fiber content, ruminants are a suitable livestock species for utilizing avocado meal and peel as feed components.

Several studies have investigated the in-vitro digestibility of avocado by-products, however, the results have been inconsistent (Skenjana et al., 2006; Negesse et al., 2009; Eliyahu et al., 2015; de Evan et al., 2020; Navarro Marcos et al., 2020). These inconcistencies likely reflect differences in avocado by-product composition, oil extraction methods, sample preservation (fresh vs. dried) and experimental design (in vitro vs. in-vivo).

One of the earliest studies evaluated the nutritional value of avocado meal for ruminants using samples from a commercial oil extraction unit in South Africa, followed by an in-situ digestibility assessment in sheep (Skenjana et al., 2006). The study reported an in-vitro organic matter digestibility (OMD) of 54%, which aligned with an effective degradability of 53-57% in the in-situ trial. The moderate degradability was likely due to the high lignin content (26% as DM) and neutral detergent fiber (NDF) lignification index of 0.50, suggesting that avocado meal is best suited for ruminants on maintenance low-production diets.
In contrast, a study conducted in Israel found that wet avocado meal exhibited significantly lower digestibility, with an in-vitro OMD of 29% and an in-vivo digestibility of 43% (Eliyahu et al., 2015). The high lignin (27%) and ether extract content (18%) likely inhibited NDF degradation in the rumen, further limiting its nutritional value.

Besides the avocado meal, incorporating avocado peels into ruminant diets can also help manage waste from avocado processing. A study assessed the in-vitro digestibility of avocado peel from Ethiopia using gas production tests with rumen fluid from non-lactating Holstein Friesian cows reported a low OMD (36.5%) compared to other fruit and vegetable peels, which typically exhibited OMD values of 70% or higher (Negesse et al., 2009). The lower digestibility was attributed to reduced short-chain fatty acid production, linked to the peel's high lignin and ether extract content (44% as DM).

The inclusion of avocado pulp and peel mixtures in livestock diets has been also studied for their potential benefits. One study found that the combination of avocado pulp and peel had a slightly higher true dry matter digestibility (87.4%) compared to peel alone (74.2%) during in-vitro ruminal fermentation (Navarro Marcos et al., 2020). This suggests that using th pulp:peel mixture could be a viable option for ruminant feeding while also reducing environmental impact and feed costs. However, this study involved by-products with relatively low lignin contents (3.5% for peel and 0.4% for the pulp:peel mixture) and low NDF lignification index (0.30 and 0.04, respectively), contrasting with materials that showed lower digestibility when lignin contents ranged from 13% to 27% and lignification values between 0.40 and 0.50 (Skenjana et al., 2006; Eliyahu et al., 2015).

Despite the high ether extract content of the peel (64%) and the pulp:peel mixture (59%), no adverse effects on in-vitro fermentation were noted at 15% inclusion level (Navarro Marcos et al., 2020). Nevertheless, when 14.8% of the avocado pulp and peel mixture was incorporated into dairy goat diets, a decrease in dry matter intake and body weight was reported, although an increase in milk fat content was nored(de Evan et al., 2020). The authors attributed the decline in intake to potential lipid peroxidation impairing feed palatability. Therefore, the high residual fat content in avocado by-products can negatively impact rumen degradability and feed intake due to the risk of lipid rancidity.
In an exploratory study in lambs, including 10% whole avocado fruit meal in the diet resulted in positive effects on weight gain without adversely affecting growth parameters or carcass traits (Job et al., 2021). Similarly, a study in Mexico demonstrated that incorporating 10% commercial avocado peel product in cattle diets, replacing maize, resulted in increased body weight after 120 days with no significant differences in feed intake ($P > 0.1$) (Mendez-Zamora et al., 2024). These findings suggest that avocado peel can be safely included at low levels in cattle diets without compromising feed consumption.

A summary of key studies is provided below:

Study	Product	OMD (%)	Lignin (% DM)	Main Observations
Skenjana et al. (2006)	Avocado meal	54	26	Moderate degradability; suited for low-production diets
Eliyahu et al. (2015)	Wet avocado meal	29	27	Very low digestibility; high fat and lignin content
Negesse et al. (2009)	Avocado peel	36.5	High	Low OMD compared to other peels; high ether extract
Navarro Marcos et al. (2020)	Pulp and peel mixture	87.4	0.4 (mixture)	High digestibility with low lignin and NDF lignification
de Evan et al. (2020)	Pulp and peel mixture	-	-	Decreased intake and body weight in goats at ~15% inclusion
Job et al. (2021)	Whole avocado fruit meal	-	-	Positive effects on lamb weight gain
Mendez-Zamora et al. (2024)	Commercial avocado peel	-	-	Increased cattle body weight without affecting intake

Importantly, although the presence of tannins and high fat content in avocado by-products poses challenges for ruminal fermentation, these components also offer potential benefits. In moderation, tannins and dietary fats have been associated with reductions in enteric methane emissions and improved nitrogen utilization efficiency in ruminants, suggesting that strategic inclusion of avocado by-products could contribute to more sustainable livestock production.

In conclusion, despite the potential benefits of avocado by-products as feed ingredients, several factors must be considered to optimize their utilization. High lignin content, residual fat, phenolic compounds, and tannins can negatively impact their nutritional value for ruminants. Efficient oil extraction is essential to minimize lipid peroxidation and preserve palatability. When organic matter degradability is moderate, avocado by-products may be most approproiate for ruminants on maintenance or low-production diets. Furthermore, the moderate presence of tannins and fats could present an opportunity to reduce enteric methane emissions and enhance nitrogen utilization. Overall, given their cost-effectiveness, potential environmental benefits, and rile in promoting circular agriculture, avocado by-products represent a promising alternative feed resource, particularly in regions facing ingredient acquisition challenges.

2.4.2 Pigs

The inclusion of avocado by-products in pig diets has gained interest due to their potential as alternative feed ingredients. A few studies have explored the effects of fresh and dried avocado products on pig health, feed intake, and growth performance. Notably, research involving the inclusion of 20% fresh avocado pulp (Grageola et al., 2010) and fresh milled whole fruit (Grageola et al., 2019; Fránquez et al., 2017), 30% fresh whole fruit paste (Hernández-López et al., 2016), and 10% dried milled whole fruit (Lemus-Avalos et al., 2020) reported no adverse health effects or drastic declines in feed intake and growth, despite concerns regarding persin toxicity. Moreover, the inclusion of 5% or 10% dried milled whole fruit has been found to enhance feed intake and body weight gain in fattening pigs (Lemus-Flores et al., 2022). These findings suggest that avocado products can be incorporated into pig diets without negatively impacting overall health and performance.
Accurate feed formulation requires an understanding of nutrient digestibility. Studies have assessed the in-vitro digestibility of different avocado fruit components for pigs (Table 6). As expected, avocado pulp exhibited higher organic matter digestibility than the stone and peel due to lower fiber content. Interestingly, nitrogen digestibility was found to be higher in avocado stones compared to pulp (77% vs. 73%), indicating the potential value of protein fraction in avocado stones. In contrast, the high dietary fiber content in avocado peel negatively impacted nutrient digestibility, as demonstrated by in-vivo digestibility studies where fresh milled whole avocado fruit led to lower total tract digestibility of organic matter compared to the fresh pulp (Grageola et al., 2010 & 2019).

Despite the existing variability in avocado samples and assessment methods across studies, it is evident that fiber from the avocado peel is a limiting factor in nutrient utilization in pigs.

Table 6 *Nutrient digestibility (%) of avocado products for pigs.*

		DM	Organic matter	Fat	Protein	Ash	Crude fiber	
Fresh pulp		84.1	83.8	83.4[1]	82.1	46.4	NA	Grageola et al., 2010 [2]
Fresh whole fruit		74.0	77.0	80.3[1]	50.0	67.1	31.4	Grageola et al., 2019[2]
Pulp	In-vitro (3)	63.1	63.5	NA	73.1	NA	NA	Ly et al., 2021
Stone		46.0	46.6	NA	77.4	NA	NA	
Peel		39.2	41.4	NA	55.0	NA	NA	

1.Acidified ether extract

2.Total tract apparent digestibility calculated by indirect method

3.Two-step in-vitro method

The high dietary fibre content of avocado meal is a limiting factor for its application in pig diets. Silage making can be an easy and cost-effective solution to increase the nutrient digestibility of Avocado meal. Studies have shown that incorporating 3% or 5% ensiled avocado meal as a wheat bran replacement in weaner pig diets does not compromise growth performance (Seshoka et al., 2020). Notably, at a 3% inclusion level, fiber fraction digestibility of the diet slightly improved compared to the control diet. For instance, the digestibility of neutral detergent fiber (NDF) and acid detergent lignin (ADL) increased from 70.2% and 68.1% in the control diet to 73.6% and 73.5% in the 3% ensiled avocado meal diet, respectively. However, this improvement was not observed at the 5% inclusion level. Additionally, supplementing pig diets containing 5% avocado meal silage with commercial carbohydrases (Axtra®) increased dry matter intake and body weight gain due to enhanced nutrient digestibility, particularly the fibre fractions (Nkosi et al., 2020). Nonetheless, since the control diet did not contain the exogenous enzyme, it remains unclear whether the improved digestibility resulted from enzyme effects on avocado meal or on other dietary ingredients. Avocado stones, another by-product of avocado processing, possess a high starch content, making them a potential energy source for pigs. Research indicates that including 10% or 20% milled dried avocado stones in pig diets does not significantly affect feed intake. However, at the 20% inclusion level, body weight gain was reduced due to lower total tract nutrients digestibility, i.e. organic matter, energy, and nitrogen (Haro et al., 2020). The presence of polyphenols in avocado stones may impair protein digestibility, indicating the need for further investigation into processing methods to alleviate these effects.

Research on the use of avocado by-products in pig diets is limited, mainly focusing on digestibility and the effects of avocado products on meat quality. While digestibility coefficients are necessary for feed formulation, the results of feed intake and growth performance of digestibility studies cannot be directly interpreted as diets were not isocaloric and isonitrogenous. Differences in the nutritional composition of the control diet and diets including avocado products existed in studies in which negative effects on feed intake were observed. For example, including 21% fresh paste of whole avocado fruit reduced dry matter content (58.2% vs 86.6%) and increased ether extract (14.5% vs 3.2%) and gross energy (20.5 vs 18.5 kJ/g) content of diet. This led to lower feed intake (2.34 vs 3.30 kg DM feed intake/day) (Franques et al., 2017). Despite these limitations, the absence of drastic declines in feed intake and growth, as well as the lack of observed health issues, suggests that avocado by-products can serve as alternative ingredients in pig diets. Further research is needed to assess their long-term effects and determine optimal inclusion levels of different avocado by-products.

In conclusion, the incorporation of avocado by-products into pig diets presents a promising opportunity for sustainable feed formulation. While studies have demonstrated that avocado meal, pulp, and stones can be included at moderate levels without adverse effects, high fiber content and polyphenols pose challenges to nutrient digestibility.

Strategies such as ensiling and enzyme supplementation may enhance nutrient utilization, but additional research is required to refine feeding strategies and establish safe and effective inclusion levels. With further investigation, avocado by-products could become a valuable component of pig nutrition, contributing to sustainable and cost-effective animal feeding practices.

2.4.3 Poultry

The inclusion of avocado by-products in poultry diets has been scarcely studied. One study examined the effects of a commercial partially-defatted dried avocado meal (AM) in broiler diets (van Ryssen et al., 2013). Avocado meal, produced by extracting oil from the whole fruit and drying it at 70°C, was used to replace maize on a one-to-one basis in diets for broilers aged 15 to 42 days. The AM inclusion ranged from 0% to 27% in the starter phase and 0% to 30% in the finisher phase across five dietary treatments. As AM levels increased, feed intake, average daily gain, and feed conversion ratio significantly decreased. At 42 days, birds on the 0% AM diet weighed 1987 g with an FCR of 1.93, whereas those on the 29.3% AM diet weighed 1001 g with an FCR of 3.67. The decline in performance was attributed to antinutritional factors such as condensed tannins and high crude fiber (CF) (van Ryssen et al., 2013). Avocado meal in this study had about 1.6 times higher crude fibre compared with maize, therefore one-to-one replacement of maize with AM remarkably increased CF content of the test diets. Additionally, replacing maize with AM increased dietary crude protein, fat, and fiber contents, making diets non-isocaloric. The 29% AM diet had higher protein (24% vs. 23%), fat (36% vs. 32%), and CF (13% vs. 4%) compared to the control diet which can partly explain the reduced feed intake. Understanding the nutrient digestibility of AM is essential for formulating isocaloric and isonitrogenous diets to assess the impacts of including AM on the performance of broilers. Despite the impaired performance, no mortality or physical signs of discomfort were observed. The lack of toxicity signs may be due to persin degradation during drying at 70°C or the naturally low persin concentration of the South African avocado cultivar used in the study.

Avocado stone is another by-product of oil extraction. Since it is rich in starch, avocado stone can replace cereal and maize in poultry feed. In broilers, avocado pulp and stone wastes were used together with pomegranate pulp to produce maize grains silage. Adding 64% of the silage on top of a commercial broiler feed positively impacted meat quality, including improved fatty acid composition, reduced ω6/ω3 ratio, lower cholesterol levels, and enhanced antioxidant activity, at a more economical cost compared to commercial broiler feed (Leontopoulos et al. 2021).

The use of avocado stones as feed ingredients for quail is limited due to their high tannin content (1.47%). Poultry can only tolerate tannins up to 0.5% in their feed (Choi et al., 2020). To reduce the tannin levels in avocado stones, processing methods such as soaking in water, boiling, peeling, or using alkaline solutions are employed. Additionally, avocado stones contain a dietary fiber fraction that is primarily insoluble (Barbosa-Martin et al., 2016). While insoluble fiber is considered inert for chickens, it can have positive effects on the function and development of the gastrointestinal tract at low inclusion levels.

In conclusion, the number of studies on avocado by-products in poultry is very limited. Reasons could be speculated about the lack of published outcomes. Avocado by-products are usually high in dietary fibre which is not favorable in poultry nutrition. Additionally, the presence of other antinutritional factors such as tannins and other phenolic compounds with negative effects on palatability and protein digestibility, and persin which is suggested to have toxin effects in birds can reduce attraction on the incorporation in poultry feed. Moreover, avocado by-products, particularly meal, have high moisture content and using such ingredients is not common in poultry. However, with the expected rise in avocado production in countries like Ethiopia, where struggling with supply and rising cost of feed ingredients, investigating the use of avocado processing by-products in poultry feed may be worthwhile. The residual fat content of avocado meal, and the starch content of avocado stone can suggest avocado by-products as a source of energy in poultry feed, while insoluble dietary fibre as exists in avocado peel can have positive effects on the development and functionality of digestive tract in poultry.

Therefore, it is essential to determine the nutritional value of avocado meal according to standard methods. By assessing the digestibility of amino acids and the metabolizable energy content of avocado meal for poultry, it would be possible to design a performance trial to study the effects of incorporating avocado meal on the performance parameters of broilers. A dose-response study could help establish the highest inclusion level of this product in broiler diets while maintaining production performance. Further investigations are required to establish the cause(s) of the poor performance of the broilers consuming AM, and whether it can be overcome and treated or not.

However, from the current study, it is concluded that the inclusion of AM in poultry diets depends on its chemical composition and prior processing to reduce tannins and other antinutritional factors, while poultry may maintain growth performance at low inclusion levels.

2.4.4 Other species

Including avocado meal of Hass cultivar from a commercial processing unit in Mexico in the diet of rabbits increased feed intake and body weight gain at 8.4% and 12.3% inclusion levels (Morales-Almaraz et al., 2023). Besides livestock, 19% avocado meal was incorporated as a source of fibre in canine food without causing any health issues (Dainton et al., 2022).

Insects offer a promising approach to organic waste treatment. Vermicomposting, which involves worms and microorganisms converting organic waste into nutrient-rich humus, represents one of the most recognized applications. Another example is the Black Soldier Fly larvae which convert organic biomass into valuable sources of protein and fat for human food and animal feed. Black Soldier Fly larvae (BSFL) can grow on a mixture of avocado pulp and stone, however, the low crude protein content (~7% as DM) limited the body weight gain of larvae. Increasing the crude protein content of substrate to 10% resulted in a favourable growth of larvae (Ben-Mordechay, et al., 2024). These larvae require a substrate with a moisture content of about 70%. Therefore, incorporating avocado meal in BSFL can prevent the need for drying. However, very little is currently known about the value of avocado meal for BSFL, the impacts of high dietary fibre content, tannins, and persin.

Highlights 2.4

- Only a few studies investigated the use of avocado by-products, i.e. dried and fresh meal, stones, peel, in feed. Their chemical composition, particularly ether extract content, shows wide variation (6–18% in meal, 4–19% in stones, and 16–50% in peel, on a DM basis), which restricts consistent feed formulation and limits their practical application.
- While avocado by-products show potential for use in maintenance or low-production ruminant diets, their high lignin and fat content, along with phenolic compounds and tannins, may inhibit fiber degradation in the rumen and limit overall digestibility.
- Pigs tolerated up to 10% dried avocado stone or 30% fresh fruit waste without negative effects, making them a promising species for valorizing avocado by-products—though higher inclusion levels may impair growth and nutrient absorption.
- Limited studies in poultry suggested that high-fiber content and antinutritional factors in avocado meal negatively affect broiler performance. Yet the high starch content of stones and growing feed demand in Ethiopia makes them worth further exploration.
- Black Soldier Fly larvae thrive on moist agro-industrial waste. The high moisture content of avocado meal and oil extraction wastewater makes these by-products promising substrates for sustainable insect protein production.
- Despite compositional variability and antinutritional concerns, especially regarding lignin, tannins, and persin, no adverse health effects have been reported in animals fed up to 30% fresh or 10% dried avocado by-products, suggesting cautious inclusion may be safe, but further research is needed to optimize use

3 Data collection and analysis

A questionnaire was used to figure out the detailed capacity and usage of avocado waste in Ethiopia. This questionnaire is attached to this report (Annex 1). Data was collected between March and June 2024. Due to privacy and data protection policies, the names and capacities of avocado processing plants are anonymized. In addition, ten samples were collected from commercial oil extraction plants located in different regions of Ethiopia (AM1-4), along with one sample from Kenya (AM5) and another from the Netherlands (Wet) (Table 7). Among these samples, there were seven avocado meal (AM) samples, two stone and one peel sample. All samples, except for the wet pomace from the Netherlands, were sun-dried. Representative subsamples were analyzed for their chemical composition at the laboratory of De Heus (The Netherlands). To date, this is the first study to assess the concentration of persin in several avocado by-products.

Table 7 *List of samples in this study.*

Name	Sample	Origin
AM1	Sundried meal from oil extraction unit1	Ethiopia
AM2	Sundried meal from oil extraction unit2	Ethiopia
AM3	Sundried meal from oil extraction unit3	Ethiopia
AM4	Sundried meal from oil extraction unit4	Ethiopia
AM5	Sundried meal from oil extraction unit5	Kenya
AM6	Sundried meal from oil extraction unit1	Ethiopia
AM wet	Fresh avocado meal from oil extraction unit6	The Netherlands
Stone1	Fresh stone	Ethiopia
Stone2	Fresh stone	Ethiopia
Peel	Sundried peel from	Ethiopia

4 Results

4.1 Chemical composition

Factors related to fruit's composition before oil extraction and the processing conditions determine the chemical composition of avocado meal (AM). As expected, the chemical composition of AM showed notable variations. Despite sun-drying, moisture content ranged from 7.6% to 19.1%, ether extract from 1.5% to 34.3%, crude protein from 6.9% to 11.3%, and crude fiber from 11% to 32% (Figure 9). The non-dried avocado meal sample (wet) had a moisture content of 73%. Despite the high moisture level, its chemical composition (% as DM) was comparable to that of sun-dried samples (Table 8). Like other by-products, AM demonstrated considerable variability across samples.

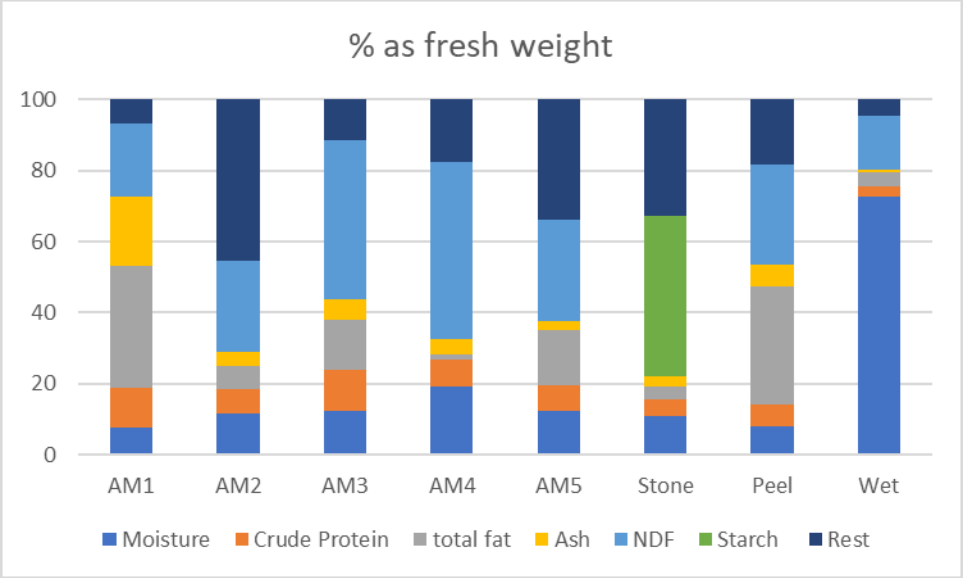


Figure 9 *The chemical composition of all samples analysed in this study (% as fresh).*

The oil extraction method determines oil yield and the amount of residual fat in AM. The high ether extract content of AM1 (37% as DM) compared to other AM samples suggests a poor oil extraction yield (Figure 9). Factors related to fruit, oil extraction process, and by-product storage conditions can vay the content of AM ether extract fraction. Method with high oil yield results in AM with low residual fat. The proportion of avocado peel and stone in AM can change AM fat content. In addition, microbial activity during AM storage can change the fat content. Inconsistencies in fat content significantly affect the available energy content for livestock which is a major constraint in feed formulation. Therefore, it is necessary to increase oil yield to reach AM with a constant level of fat. Otherwise, categorisation of AM according to the processing units into high, medium, and low fat can facilitate their application in feed.

In this study, avocado peel had a higher ether extract content compared to avocado stone and meal (Figure 9). The ether extract content of peel and stone were 36.0% (as DM) and 3.7% (as DM), respectively. This high ether extract content in the peel aligns with previous studies, where avocado peel collected in Spain (Navarro Marcos et al., 2020) and Ethiopia (Negesse et al., 2009) contained 58.9% and 44.0% ether extract (% as DM), respectively (Table 8). Variations in lipid content may be influenced by cultivar, origin, and oil extraction methods. Additionally, differences in laboratory methodology could contribute to these variations.

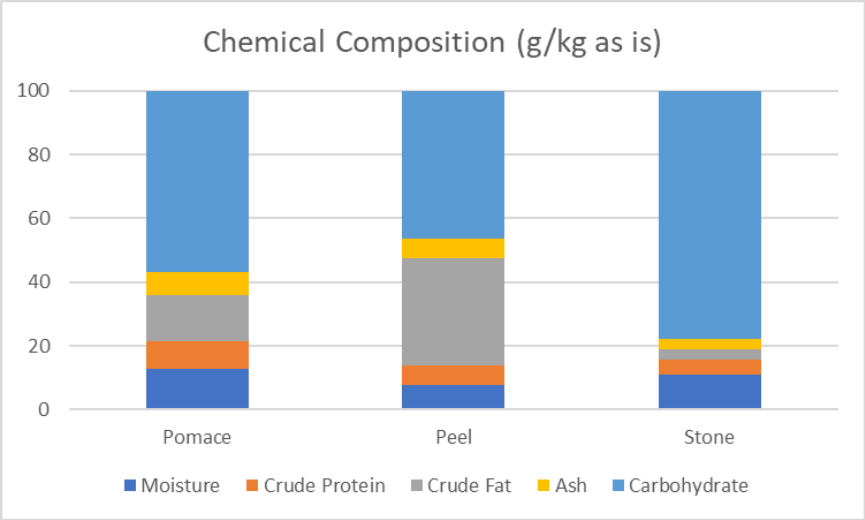


Figure 10 *Chemical composition of different sun-dried avocado by-products in this study. Values for pomace are the average of five different samples (standard deviations of moisture, crude protein, ether extract, ash, and carbohydrates were 4.1, 2.2, 12.5, 7.0, 20.5), while values for peel and stone are based on the results of one sample. The amount of carbohydrate is calculated as the remaining fraction after deducting the values of other nutrients.*

Contamination of the peel with pulp can increase its ether extract. The peel samples in this study and Negesse et al. (2009) were sun-dried after collection, while Navarro Marcos et al. (2020) used washed and pulp-free samples and still observed a high ether extract content after eliminating the effects of potential contamination of peel with pulp. The presence of peel in the avocado meal can increase its ether extract fraction, potentially impacting its nutritional profile. Further research is needed to analyze the ether extract components of avocado peel to differentiate between metabolizable lipids and non-metabolizable compounds like waxes and cutin.

Table 8 *Chemical composition of avocado peel analysed in this study and values from the literature.*

	DM	Crude Protein [1]	Ether extract	Ash	NDF	ADL	ADL/NDF
Peel[2]	92.2	6.7	36.3	6.6	30.4	15.4	0.5
Negesse et al. 2009	24.8	7.1	43.7	8.7	26.4	12.5	0.5
Navarro Marcos, et al. 2020	23.6	9.9	58.9	NA	11.5	3.5	0.3
Mendez-Zamora et al., 2024	NA	7.0	15.5	7.6	42.9	NA	NA

(1) Crude Protein = Nitrogen * 6.25
(2) Analysed in this study

According to Table 9, except for AM1, the ash content of AM samples was between 3-7% (as DM). The high ash content of AM1 suggests potential contamination with soil. Washing the avocado fruit before oil extraction and preventing contamination of AM with soil can prevent the rise in ash content.

The peel sample in this study had a lignification rate (0.51 ADL:NDF) comparable to previous studies (Table 8). The peel present in avocado meal influences its chemical composition, particularly in terms of fibre content. Except for AM1 which has a remarkably low ADL content (1.3% as DM) and resulted in a low lignification rate (0.06), the lignification rate in the other AM samples was between 0.37-0.58. Since lignin is associated with avocado peel rather than pulp, the low lignification rate of AM1 compared to other AM samples suggests the presence of less peel. The high lignification rate of other AM samples (AM2-AM5) associated with the presence of peel can limit its application in ruminants as well as in monogastric diets. According to the target livestock species, it is possible to study different physical, chemical, and biological processing methods to increase lignin digestibility for livestock.

Table 9 *The chemical composition of five sun-dried (AM1-AM5) and a wet avocado meal sample analysed in this study (% as DM).*

	DM	Crude Protein	Ether extract	Ash	Crude fibre	NDF	ADL	sugar
AM1	92.4	12.1	37.1	21.1	11.9	22.5	1.3	3.4
AM2	88.3	7.8	7.3	4.3	10.6	29.1	10.7	2.7
AM3	87.5	12.9	16.0	6.9	26.8	50.9	24.3	0.6
AM4	80.9	9.4	1.9	5.5	32.1	61.5	35.2	0.0
AM5	87.7	8.1	18.0	2.7	20.9	32.5	12.6	0.8
Wet	27.3	10.1	14.6	2.5	27.2	55.6	32.4	NA

The fatty acids profile of samples was analysed in this study (Figure 11). The low fat content of AM4 and the stone samples prevented assessing their fatty acids profile. In all avocado meal samples except AM5, the residual fat was mainly (~70%) composed of oleic acid (C18:1, 49-60 % total fat) and palmitic acid (C16, 13-23% total fat) which is consistent with previous findings. For example, avocado meal from a commercial avocado processing unit in Mexico contained 68% oleic acid (18:1, 50%) and palmitic acid (16:0, 18%), as well as 21% linoleic acid (18:2) (Zuñiga-Martínez et al., 2021). Similarly, when full-fat pulp and peel were mixed at 81:19, 71% of fatty acids were oleic (57% as total fat) and palmitic (14% as total fat) acids (de Evan et al., 2020). Therefore, avocado meal fat mainly consists of unsaturated long chain fatty acids, particularly oleic acid.

Interestingly, despite similar fatty acid profiles, there were large differences in ether extract (fat content) across samples. The pulp-peel mixture in de Evan et al. (2020) had a high ether extract (64% DM), whereas the commercial avocado meal in the study of Zuñiga-Martínez et al. (2021) contained only 14% ether extract (DM). Since pulp is the primary fat source, a higher ether extract was expected in pulp-rich samples, and the ether extract content of commercial avocado meal is comparable to avocado meal samples in our study. The similarity in fatty acid composition between partially defatted avocado meal samples (AM1-3) and those from previous studies (Zuñiga-Martínez et al., 2021) suggests that processing reduces total fat but does not significantly alter its composition.

The peel sample and AM5 showed different fatty acid profiles compared to other AM samples. These two samples contained very low levels of oleic and palmtic acids, while linoleic acid was the main fatty acids, as well as heneicosanoic acid (C21:0). The wet sample in our study and AM2 contained 15% (in total fat) linoleic acid similar to the avocado meal in the study of Zuñiga Martínez et al. (2021). Unlike the other samples, which were collected in Ethiopia, the AM5 sample was sourced from an oil extraction facility in Kenya. The differences in fatty acid profiles could also be attributed to cultivar variation and origin, as well as lipid peroxidation which can change fatty acid profile.

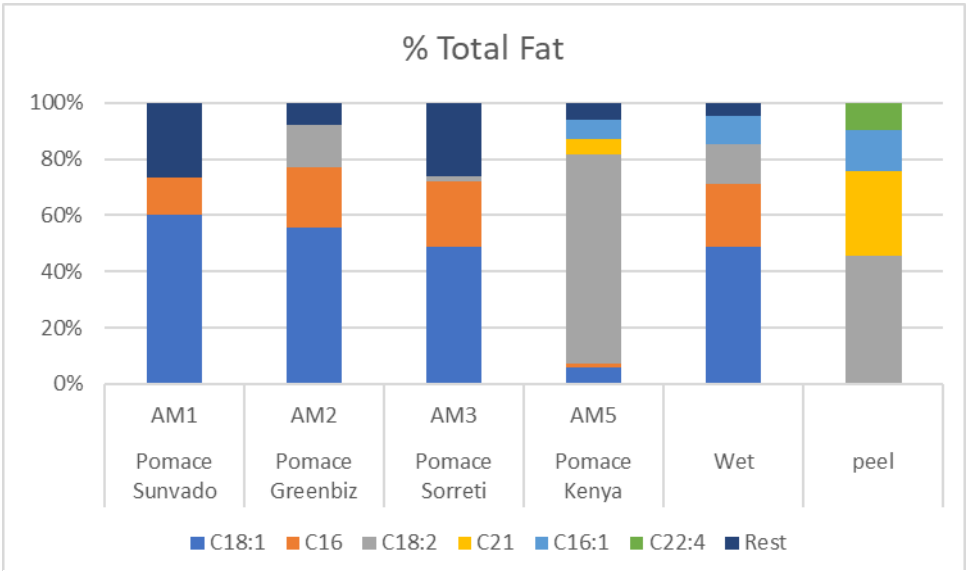


Figure 11 *Fatty acid profile of different avocado products analysed in this study.*

Table 10 compares the chemical composition of avocado stone in our study with the published results. Except for a sample with very different results (Velázquez-González, et al 2023), the chemical composition of stone in our study was comparable to others, suggesting avocado stone as an ingredient with low crude protein and fat, while high carbohydrate. The stone sample in our study contained 45% starch, while avocado meal and peel have fibre as the main fraction of carbohydrates. Assessing the starch digestibility of avocado stone can be interesting to determine its nutritional value as a source of energy for monogastric.

Table 10 *Chemical composition of avocado stones analysed in this study and from the literature.*

Citation	Origin (Cultivar)	Moisture	Ether extract	Crude protein	Crude fibre	Ash
Analysed in this study	Ethiopia[1]	10.9	3.7	5.5	5.1	3.3
Tugiyanti et al., 2019	Indonesia[2]	11.8	7.3	5.8	3.1	2.7
Velázquez-González, et al.2023	Mexico (Mill)[3]	2.8[c]	19.4	4.6	69.2[a]	2.3
Pahua-Ramos et al., 2012	Mexico (Mill)[4]	4.0	4.6	4.9	6.7	2.3
Haro et al., 2022	Spain[5]	11.0	4.2	8.8	10.8[b]	5.8

1: sundried, 2: Watersoaked, boiled, skinned, and dried, 3: freeze-dried, 4: Oven-dried, 5: not available

a Total dietary fiber

b Acid detergent fiber

The tannins content of two sun-dried and one wet avocado meal and a peel sample was assessed in this study (Table 11). The tannins content of peel (0.8 % as DM) was higher than the sun-dried AM samples. The concentration of tannins in the wet product was the highest (1.5 % as DM) compared to the AM4 (0.2% as DM) and AM5 (0.15% g/kg as DM). The concentration of tannins was not assessed in other samples of this study. In general, when an ingredient has higher than 5% tannin (as DM) is considered excessive even for ruminants (reviewed by Bhat et al., 2013) indicating that the concentration of tannins in samples was acceptable. To reduce the tannins further, one of the feasible approaches is soaking, peeling, and boiling which has been shown to be effective in avocado stones (Runyogote et al., 2021), while it is a feasible method as long as stones remain separated from AM.

Table 11 *Tannins concentration of avocado products in this study.*

	Moisture (%)	Tannins mg/kg
AM4	19.1	1200
AM5	12.3	1520
Peel	7.82	7180
Wet	72.7	4000

4.2 Persin concnetrations

In the current study, the concentration of persin was assessed in the same samples (Table 12) by liquid chromatography-mass spectrometry. In general, the concentration of persin was higher in avocado peel and stone samples compared to avocado meal samples which is consistent with previous studies (Dainton et al., 2022). Except for an avocado meal with very low (AM4, 0.006 mg/g DW) and a sample with very high (AM5, 7.9 mg/g DW) persin levels, the rest of the avocado meal samples in this study contained 0.3-0.9 mg/g (as DW) persin. To our knowledge, the only published result of the persin concentration of avocado meal is related to a dried sample from a commercial avocado processing unit in the USA where the concentration of persin was lower than the detection limit of the test (0.01 mg) (Dainton et al. 2022). Two of the samples in this study, AM1 and AM6, were collected from the same oil extraction unit in Ethiopia at different times. While both samples contained less than 0.1% persin (as DW), the persin concentration varied by about 40% indicating the existing batch-to-batch variations.

Another finding of this initial study was the higher persin content of the only wet avocado meal sample (Wet AM, 4.7 mg/g DW) compared to sun-dried avocado meal samples except AM5. This wet avocado meal sample was obtained from an avocado processing unit in the Netherlands and stored in the fridge after collection at the oil extraction unit. Upon arrival at the laboratory, the sample was frozen and stored in –18ºC until freeze-drying. The lower persin content in sun-dried compared to the wet avocado meal suggests the susceptibility of persin to sunlight, heat, and drying. However, we cannot rule out other reasons such as different persin levels of fruit, since the wet AM sample and AM5 had different origins compared to other samples in our study.
If we assume sun-drying reduces persin concentration compared to high persin in the wet sample, this contrasts with findings from a thermostability study of extracted persin (Permal et al. 2022), where pure persin was stable up to 130ºC. This thermostability study was executed after observing the reduction in avocado stone persin levels by extruding at 130ºC (0.7 mg/g) compared to freeze-dried (1.8 mg/g) or oven-dried (1.7 mg/g at 70ºC) avocado stone (Permal et al., 2022). Persin concentration in freeze-dried avocado stone from the market in the USA was 0.1 mg/g which is much lower than the result of sun-dried avocado samples in our study and the study of Permal et al. (2022). This inconsistency can be attributed to factors such as variabilities in the avocado cultivar and origin, as well as the methods used for persin quantification. Besides that, differences in processing could affect the persin content as well. Factors such as the rise in temperature during mechanical pressing and the presence of peel and stone in the by-products.
In spite of the difference in persin levels of the two stone samples in our study, 1.1 and 3.6 mg/g, these results are comparable to observed values of Hass avocado from Mexico, 3.2 mg/g DW (Rodriguez Sanchez et al., 2019), and from New Zealand 1.7 mg/g DW (Permal et al., 2023). Therefore, the presence of peel and stone in the oil extraction by-product can remarkably increase the persin concentration which is not favourable. Removing stones and peel prior to oil extraction and/or separating peel and stone from meal after oil extraction need to be considered.

Table 12 *The concentration of persin (mg/kg dried weight) in different samples in this study by using liquid chromatography mass spectrometry.*

	mg/g DW
AM1	0.924
AM2	0.338
AM3	0.658
AM4	0.006
AM5	7.945
AM6	0.581
Wet AM	4.720
Peel	2.649
Stone1	3.560
Stone2	1.131

Research to date has not yet determined the exact toxic doses of persin in different species. Outcomes of studies on the bioactivity of persin are inconsistent since the toxic effects and health-promoting effects have been observed at similar doses. At 60-100 mg/kg BW uptake of persin was associated with mastitis and myocardial lesion (Butt et al., 2006; Oelrichs et al., 1995) while at 100 mg/kg BW persin intake has been associated with liver protection effects (Kawagishi et al., 2001). Additionally, persin has been quantified in avocado pulp of different cultivars 0.1-1.4 mg/g as fresh weight (Rodriguez-Lopez et al., 2015; Salinas-Salazar et al., 2016), while avocado is safely consumed by humans. Evidence from the few published studies on the application of avocado products in different livestock species indicates the absence of negative effects on animal health even in high inclusion levels such as 210 g/kg (Franques et al., 2017) or 300 g/kg milled whole fruit avocado in finishing pigs (Hernandez-Lopez et al., 2016), 200 g/kg fresh avocado pulp in pigs (Grageola, et al., 2010), Up to 55 g/kg dried avocado stone (Olabisi et al., 2021) and up to 300 g/kg dried oil extraction by-product containing the whole fruit (van Ryssen et al., 2021) in the diet of broilers was not associated with mortality. However, persin concentration was not assessed in these studies.

In addition, including 19% dried avocado meal from a commercial processing unit in the USA was not associated with any negative health effects in dogs (Dainton et al., 2022) while the persin concentration of this product was lower than 0.01 mg. Since studies on persin toxicity have been mainly conducted in laboratory animals and mammals, it is not possible to easily extrapolate those outcomes to other species such as chickens. Besides this, persin together with other acetogenins have antibacterial effects which might be helpful for livestock health. Therefore, it is necessary to conduct safety studies on avocado by-products and determine the toxic dose for different livestock species. Only then it would be possible to provide robust recommendations on the application of avocado by-products in feed.

5 Recommendations on animal application

This study provides the first comprehensive analysis of the chemical composition and variability of by-products from avocado processing units in Ethiopia, with a particular focus on persin levels in commercial oil extraction by-products. The findings highlight the potential of avocado by-products as feed ingredients while emphasizing the need for further research to address variability and safety concerns. **Any recommendations for incorporating avocado by-products into animal feed should account for the significant variability in their chemical composition.**

Table 13 *Potential Use and Considerations of Avocado By-Products in Animal Feed.*

Component	Suitability	Description
Meal	Yes	• But limited by unsaturated fatty acids (ruminants) • Fat and fibre, and beneficial bioactive properties (pigs and poultry)
Peel	Limited	• Limited for cattle/pigs by lignin, persin, and other ANFs content • Not suitable for poultry due to lignin, persin, and other ANFs content
Stone	Yes	• Source of starch as well as ANFs
Persin levels	< 1g/kg DW (Meal)	• The exact toxic dose is unknown, persin concentration in ETH pomace samples was below 1g/kg DW
Max inclusion levels (based on literature)	30% (W/W)	• Based on stones or meals in the diet
Replacement of ingredient (example)	Wheat by-products and cereals	• Energy/fibre sources such as wheat bran • stone and meal can replace cereals and maize

Avocado Meal for Ruminants:
- Avocado meal shows promise as a feed ingredient. Moderate neutral detergent fiber (NDF) levels (e.g., 22.5–32.5%) and crude protein content (7.8–12.9%) makes it comparable to wheat bran.

-Low acid detergent lignin (ADL) levels (e.g., 1.3%) indicate higher digestibility, while high ADL levels (e.g., 35.2%) reduce energy availability.

-The residual fat in avocado meal is primarily composed of oleic acid (49–60%) and palmitic acid (13–23%). Oleic acid has a lower negative impact on rumen fermentation compared to other unsaturated fatty acids, while palmitic acid is favorable for rumen fermentation. However, avocado peel contains high levels of linoleic acid (46%) and heneicosanoic acid (30%), which may negatively affect fiber digestibility and microbial activity.

Avocado Stone for Monogastrics:
-Avocado stone can replace maize and cereals in monogastric diets, but its use is limited by anti-nutritional factors such as tannins and probably persin.

-Studies in mice suggest low toxicity, with an oral LD50 of 1767 mg/kg body weight for oven-dried milled avocado stone. Feeding trials with up to 9% inclusion levels in poultry diets showed no harmful effects on hematology parameters, while the toxic dose has yet to be determined.

Challenges and Opportunities:
-Variability in nutrient composition and anti-nutritional factors necessitates careful processing and inclusion strategies.

-High moisture content in avocado meal requires conservation methods such as drying or ensiling, with moisture reduction to 50–75% and supplementation of water-soluble carbohydrates for successful ensiling.

-Gradual introduction and inclusion levels of up to 20% of total dry matter are recommended to balance nutrient intake and prevent negative effects on animal health and performance.

Alternative Valorization Methods:
-Avocado wastewater (AWW) can be spray-dried into a powder with high antioxidant activity, suitable for food preservation.

-AWW can also serve as a moisture source for Black Soldier Fly larvae (BSFL) rearing, offering a sustainable waste management solution and producing protein-rich insect biomass for animal feed.

Toxicity Concerns:
-Persin, a natural fungicidal toxin in avocado by-products, poses a significant limitation for feed applications. Methods to reduce persin levels, such as heating, fermenting, or leaching, are essential for safe use.

The study underscores the potential of avocado by-products as sustainable feed ingredients, particularly as a source of energy for ruminants and monogastrics. However, variability in composition, anti-nutritional factors, and toxicity concerns necessitate further research to optimize processing methods, determine safe inclusion rates, and evaluate digestibility and nutrient availability. By addressing these challenges, avocado by-products can contribute to a circular economy, reducing agricultural waste and providing cost-effective feed solutions.

6 Other applications of avocado by-products

In addition to its potential for use in animal feed, avocado waste can be turned into valuable products and energy through various valorization routes, contributing to a circular economy and reducing the environmental impact (Figure 12). Here are some possible uses: i) in the food industry for sustainable packaging (biodegradable plastics) and the production of functional food products, ii) in the production of cosmetics and pharmaceuticals due to its antioxidant properties, iii) for soil conditioning and composting, providing a nutrient-rich soil conditioner that can improve soil health and boost crop yields, and iv) can be used as fuel for electricity generation, biofuels, such as biodiesel and bioethanol, which can be used as renewable energy sources.

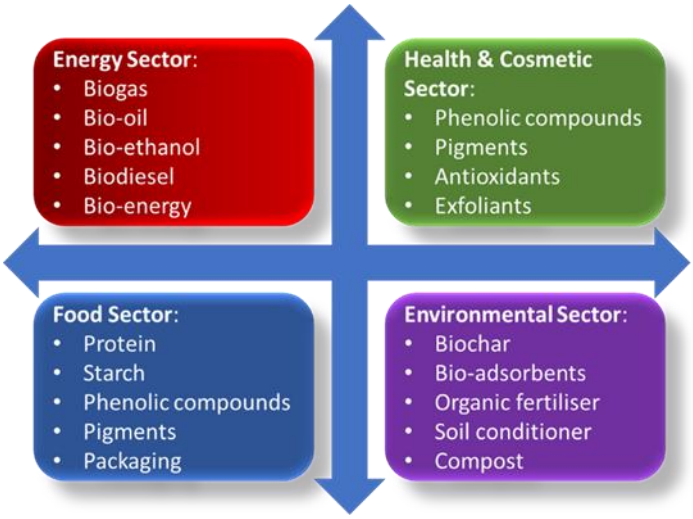


Figure 12 *Summary of potential use of avocado waste by sectors (source: own).*

7 Environmental impact of avocado waste

The environmental impacts of avocado waste could be significant if it is not properly managed, given the substantial volume of by-products such as peels, stones, and pulp generated during avocado production and processing. These by-products represent a considerable loss of resources like water and arable land used in avocado cultivation. The improper disposal of this organic waste can lead to substantial landfill use, contributing to methane emissions—a potent greenhouse gas—when decomposed anaerobically. Furthermore, if not managed properly, the leachate from avocado waste can lead to soil degradation and water pollution, adversely affecting aquatic ecosystems and potentially contaminating water sources. However, avocado waste has the potential to enhance soil health when used as compost or mulch, improving soil structure, fertility, and moisture retention. Processing methods such as mechanical pressing and cold pressing of avocado oil are more environmentally friendly as they generate less hazardous waste compared to chemical extraction methods. Moreover, by diverting avocado waste from landfills to applications like biogas production, greenhouse gas emissions can be significantly reduced.
Overall, effectively managing avocado waste by integrating it into a circular economy model not only mitigates these environmental concerns but also promotes sustainability by creating a closed-loop system where waste is minimized, and resources are optimally utilized.

8 Business Case

The business case for utilizing avocado waste as feed ingredients in Ethiopia focuses on developing a cost-effective, environmentally sustainable, and nutritionally beneficial solution. Ethiopia's livestock industry, particularly poultry and ruminant production, currently relies on feed ingredients such as grain bran and oilseed cakes, but rising costs and supply limitations are creating significant challenges for producers. With increasing local avocado production, substantial quantities of avocado pomace, peels, and stones are available as by-products from the oil extraction industry, presenting a unique opportunity to reduce costs and improve sustainability within the livestock feed sector.

The potential benefits of these avocado by-products are considerable. According to figure 9, dried avocado meal is a fiber-rich ingredient that contains a moderate amount of protein and has high energy content. Additionally, avocado stones serve as a source of starch, and along with peels these by-products contain essential minerals, fatty acids, and bioactive compounds. This suggests that avocado processing by-products could be alternative ingredients to complement or substitute conventional feed ingredients. However, the bioactive compounds can have antinutritional effects, particularly at high inclusion levels. Therefore, processing steps are necessary to mitigate any negative impacts on livestock growth and production performances and health, as well as the safety of their products. These by-products introduce affordable locally produced ingredients to feed manufacturers reducing feed costs and enabling farmers to achieve greater profitability.

Table 14 *Comparison of estimated prices of most common ingredients used by the Ethiopian feed industry.*

INGREDIENT	Price (Fresh) 2022	Price (Fresh) 2023	Price (Fresh) 2024	DM content	Protein Content
				%	
	ETB / Tonnes	ETB / Tonnes	ETB / Tonnes		%
Soybean cake	43500	37750	43000	90	49
Noug cake	30550	30500	31250	90	28
Wheat bran	16000	18000	20000	87	17,3
rapeseed cake	24500	23000	23500	90	36
Ground nut cake	32600	34000	35000	90	45
Sunflower cake	24650	25000	25000	90	30
Cotton seed cake	20000	21500	38000	92	35
Cassava bran	19500	19000	18500	87	4
Maize white	25000	35000	33500	88	8
Wheat middling	22000	23000	24000	89	17

Rather than letting these by-products go to waste, processing them into animal feed offers a low-cost, high-nutrient supplement for livestock, substituting part of traditional feeds. From an operational perspective, the feed companies require establishing partnerships with avocado oil extraction facilities to ensure a reliable waste supply focus on i) Consistent Quality and Nutritional Value (Processing Standards and Nutritional Composition) ii) Safety and Toxin Management (WUR advice according with analysis results), iii) Reliable Supply Chain (Consistent seasonal availability & Logistic) Feed Regulations, and iv) Capacity for Innovation and Scaling.

At the moment of the study, SUNVADO was the only operating factory with a standard procedure for waste classification, separation and treatment (meal sun drying).

The market potential for avocado by-products is huge but future investment in drying, grinding, and detoxification equipment will be critical for transforming the waste into a safe, stable, and effective feed ingredient. While challenges exist, such as seasonal fluctuations in avocado production and potential market hesitance toward unconventional feed sources, these can be mitigated through diverse supplier contracts, safety testing, and strategic marketing campaigns. Overall, the business anticipates a favorable return, thanks to significant cost savings, reduced environmental impact, and enhanced livestock productivity. A phased implementation approach, beginning with pilot trials and scaling up over time, will enable a manageable and effective market introduction.

8.1 Criteria for Selecting Agro-Industry Suppliers

To ensure a reliable and high-quality supply of avocado by-products, potential suppliers can be evaluated based on the following criteria:

1. Proximity and transportation time - shorter distances ensure faster delivery, less deterioration of by-products and lower costs for logistics.
2. Road conditions and safety - Assessing infrastructure reliability and accessibility.
3. Supplier credibility – consistency in product quantity and quality
4. By-product conditions – evaluating dry matter content and hygiene standards
5. Pricing – competitive cost structures to maintain economic viability

In our specific case, considering proximity and transportation time, Factories 1, 3, and 4 may be less suitable sources of avocado waste for Alema's feed factory, as they are located over 288 km from the plant. However, factors such as by-product quality, dry matter content, and pricing could make them viable options in the future. For instance, Factory 1 supplies high-quality by-products under strict hygienic conditions, and its formal operations ensure consistency in both quality and quantity, making it a potential supplier worth reconsidering despite the distance.

Factory 2 appears to be the most viable option in terms of proximity and transportation efficiency. However, its informal operations and irregular production volumes present challenges for consistent and reliable sourcing. If Factory 2 transitions to a more structured production model, it could become a strong candidate for avocado by-product (ABP) supply (Table 15).

Since waste distribution and transportation in Ethiopia follow various arrangements and are often negotiated on a case-by-case basis, determining a fixed cost per kilometre and per tonne is challenging. Nevertheless, we can make a rough estimation by extrapolation of average costs for transporting feed ingredients or by-products in Ethiopia, which is usually done by Isuzu trucks, with a capacity of up to 7 tonnes. The quoted transport price for this type of truck in Ethiopia is around 10 ETB/km/tonne.

Table 15 *Distance from avocado plants to Alema Koudijs Feed Plc and estimate ABP prices.*

Avocado	Distance to Feed plant	Residue	ABP price (only transport*)
	(Km)	(Tonnes)	ETB/Tonnes
Factory 1 (SUNVADO)	288	400	2880
Factory 2 (GREENBZ)	42	1200	420
Factory 3 (SORETI)	394	4800	3940
Factory 4 (YBM)	328	3000	3280

**Based Transport cost of 10 ETB/T/Km*

8.2 Sustainable Feed Innovation: A Business Case for Avocado By-Products

As global demand for sustainable livestock feed continues to grow, there is a significant opportunity to utilize agricultural by-products as cost-effective, environmentally sound alternatives to traditional feed ingredients. This study has focused on the repurposing of avocado wastes as feed ingredients, since avocado production is rapidly expanding, particularly in Ethiopia and Kenya. By transforming discarded avocado peel, stone, and pulp residues into animal feed, this business model addresses multiple challenges, including waste management, feed cost reduction, and import dependency.

The Netherlands, a leader in agri-food innovation, presents a strategic entry point for scaling up research, technology, and partnerships in waste-to-feed solutions. By showcasing the environmental and economic advantages of avocado by-products, this model can attract investment, policy support, and collaboration from international stakeholders, positioning itself as a scalable and replicable approach in the global feed industry.

Below is an in-depth look at how this business model supports a circular economy, improves livestock productivity and health, and expands market potential beyond avocado waste in the current context.

Circular economy model
The integration of avocado by-products into animal feed aligns with a circular economy model, as agricultural waste is repurposed to create value instead of becoming waste. This incentive significantly reduces landfill waste and lowers methane emissions associated with organic waste decomposition. Furthermore, replacing conventional feed ingredients with locally available avocado by-products decreases reliance on imported feed, which often has a high environmental footprint due to transportation and resource-intensive production. This approach not only benefits the environment but also enhances circularity by creating a closed-loop system that supports local farmers, reduces the costs of waste disposal and promotes efficient resource utilization in livestock farming.

Nutritional and Production Benefits
Using avocado by-products as a feed ingredient may offer nutritional advantages for livestock, particularly if feed resources are scarce, expensive or based on by-products from agricultural products. Our research suggests that avocado waste contains valuable nutrients, including fibre, fats and beneficial bioactive properties, which can enhance weight gain, feed efficiency, and overall productivity in livestock.

Future projects could explore further optimization of feed formulations by combining avocado by-products with other agricultural residues to create balanced and cost-effective rations, for ruminants, incorporating avocado by-products as ingredients in TMR rations presents an efficient and sustainable way to utilize these residues effectively. Moreover, processing methods such as drying, pelletizing, and ensiling can improve storage, handling, and digestibility, making it easier to integrate these by-products into existing feed systems. These advancements contribute to a resilient and cost-effective livestock feed sector while enhancing animal health and production performance.

Assessing the opportunity to incorporate avocado by-products into monogastric diets requires the determination of their nutritional values and executing dose-response studies to determine the optimum inclusion levels. In this regard, avocado stones can be an interesting source of starch, while avocado meal can be incorporated in low inclusion levels providing nutrients as well as insoluble fiber improving the development and function of the digestive tract. Reaching by-products with constant and predictable content of nutrients and antinutritional factors is necessary to facilitate their incorporation in diets of poultry and pigs.

International Stakeholders

This business model is not only relevant for Ethiopia but also holds great potential for Kenya, the leading avocado producer in Africa and other East African countries. By demonstrating the economic and environmental benefits of using avocado by-products as a sustainable feed ingredient, the business can attract international stakeholders, including feed manufacturers, livestock producers, and sustainability-driven investors.

Additionally, the concept can be expanded to include other fruit waste streams as alternative feed ingredients. Table 16 illustrates the potential of various fruit by-products based on their nutritional composition, further supporting the feasibility of waste-based feed solutions. By broadening the scope beyond avocados, the business can tap into multiple waste streams, increasing its impact on reducing food waste while enhancing livestock feed sustainability across different regions.

Table 16 *Nutritional composition of fruit by-products.*

By-product	Dry Matter (%)	Crude Protein (%)	Crude Fat (%)	Carbohydrates (%)	Fiber (%)	Ash (%)
Avocado peel	76.21	3.04	3.04	76.21	-	4.32
Mango peel	80-85	3.6-5.0	2.2-3.0	43-81	6.5-7.5	2.5-3.5
Mango seed kernel	85-90	6.0-8.0	7.0-15.0	72.55	2.0-3.0	2.0-3.0
Pineapple peel	86-88	3.0-4.5	0.5-1.5	40-50	20-25	3.5-5.0
Banana peel	85-90	6.5-8.0	6.0-8.0	70-80	30-35	8.0-10
Banana pseudostem	6-8	3.0-4.0	1.0-2.0	55-60	20-25	15-18

9 Conclusions

This study highlights the growing Ethiopian avocado industry as a promising source of by-products, which currently remain underutilized. With increasing production and seasonal variations, avocado by-products—particularly the meal remaining after oil extraction—can help address Ethiopia's feed ingredient demand-supply gap. Besides variability in the chemical composition, which requires specific attention, the practical use of these by-products faces challenges such as transportation costs, short shelf life, and the labor-intensive processing required for effective utilization. Addressing these logistical and processing constraints, especially through drying, is critical for enhancing their viability as feed components.

For ruminants, avocado residues, including dried meal, peels, and stones, offer significant potential as sustainable, cost-effective feed ingredients. Dried meal, with its moderate level of fiber, energy-dense fats, and essential minerals, can be incorporated into diets at levels of 5-10% of total dry matter, balanced with traditional feed components like brans and oilseed cakes, and in case of more standardised products the inclusion could be up to 20%.

For Poultry, avocado stones can be a substitute for cereals and maize, reducing food-feed competition. After processing to reduce the risk of tannins and probably persin, the digestibility of the starch and fat needs to be determined. At low inclusion levels, dried avocado meal can contribute to the fat and protein content of diets as well as provide insoluble fibre for the development of the digestive tract.

Incorporating fresh avocado meals and the wastewater in Black Soldier Fly larvae substrate can be a feasible valorisation method as well, while the knowledge on the role of anti-nutritional factors and their nutritional values is limited.

Variability in the nutrient composition of avocado residues and the credibility of suppliers are critical considerations for consistent feed quality. Establishing quality standards and working with reliable suppliers will be key to successfully integrating these by-products into livestock feed formulations.

By utilizing avocado by-products effectively, Ethiopia's livestock industry can reduce feed costs, enhance productivity, and minimize environmental waste from the avocado processing sector. This innovative approach supports sustainable agriculture by transforming agricultural residues into valuable resources, benefiting both the feed industry and the environment.

References

Abebe, A., B. Kuma, and L. Zemedu. (2022). Assessment of postharvest loss of Avocado at producers level (case of Wolaita and KembataTembaro zones). J. Agric. Crops (84): 364–374.

Abduselam Faris. (2016). Review on Avocado Value Chain in Ethiopia. ISSN 2224-6096 (Paper) ISSN 2225-0581 (online) Vol.6, No.3, 2016.

Akan, S. (2021). Phytochemicals in avocado peel and their potential uses. Food and Health, 7(2), 138-149. https://doi.org/10.3153/FH21015
Arukwe, U., Amadi, B. A., Duru, M. K. C., Agomuo, E. N., Adindu, E. A., Odika, P. C., ... & Anudike, J. (2012). Chemical composition of Persea americana leaf, fruit and seed.

Barbosa-Martín, E., Chel-Guerrero, L., González-Mondragón, E., & Betancur-Ancona, D. (2016). Chemical and technological properties of avocado (Persea americana Mill.) seed fibrous residues. Food and Bioproducts processing, 100, 457-463.

Ben-Mordechay, T., Gutman, R., Shaltiel-Harpaz, L. and Opatovsky, I., 2024. How to reduce waste using black soldier fly larvae and produce a high-quality product. Journal of Insects as Food and Feed, 1(aop), pp.1-8.

Bhuyan, D.J., Alsherbiny, M.A., Perera, S., Low, M., Basu, A., Devi, O.A., Barooah, M.S., Li, C.G. and Papoutsis, K., 2019. The odyssey of bioactive compounds in avocado (Persea americana) and their health benefits. Antioxidants, 8(10), p.426.

Biazin, B., Haileslassie, A., Zewdie, T. et al. (2018). Smallholders' avocado production systems and tree productivity in the southern highlands of Ethiopia. Agroforest Syst 92, 127–137. https://doi.org/10.1007/s10457-016-0020-2

Butt, A. J., Roberts, C. G., Seawright, A. A., Oelrichs, P. B., Macleod, J. K., Liaw, T., Y, E, . . . Sutherland, R., L. (2006). A novel plant toxin, persin, with in vivo activity in the mammary gland, induces Bim-dependent apoptosis in human breast cancer cells. Molecular Cancer Therapeutics, 5(9), 2300-2309. https://doi.org/10.1158/1535-7163.mct-06-0170

Carman, R.M. and Handley, P.N., 1999. Antifungal diene in leaves of various avocado cultivars. Phytochemistry, 50(8), pp.1329-1331.

Chaix-Bar, M., Ndambi, A., El Deen, S. N., de Raad, S., Mohammed, E., & Koomen, I. (2023). Feasibility study: black soldier fly production for animal feed in Ethiopia (No. 009). Stichting Wageningen Research Ethiopia

Choi J, Kim, Woo K, (2020). Dietary application of tannins as a potential mitigation strategy for current challenges in poultry production: A review. Animal 10: 239. http://doi.org/10.3390/ani10122389

Contreras Briceño Luz Karime and Katherinne Jurley Barajas Cárdenas. Aprovechamiento de residuos aguacate generados en centro abastos de Bucaramanga para la producción de aceites esenciales. Universidad Nacional Abierta y a Distancia. Escuela de Ciencias Agrícolas, Pecuarias y del Medio Ambiente Ingeniería Ambiental. Bucaramanga, 2021.

Craigmill, A. L., Seawright, A. A., Mattila, T., & Frost, A. J. (1989). Pathological changes in the mammary gland and biochemical changes in milk of the goat following oral dosing with leaf of the avocado (Persea americana). Aust Vet J, 66(7), 206-211. https://doi.org/10.1111/j.1751-0813.1989.tb09809.x

CSA (Agricultural sample survey 2018 Central Statistical Agency). (2018). The federal democratic republic of Ethiopia. 2018 report on area and production of major crops, statistical bulletin 586 IMF Staff Country Reports. 18. 10.5089/9781484338506.002.

CSA (2021). Agricultural productivity and inflation.

de Evan, T.; Carro, M.D.; Yepes, J.E.F.; Haro, A.; Arbesú, L.; Romero-Huelva, M.; Molina-Alcaide, E. 2(2020). Effects of Feeding Multinutrient Blocks Including Avocado Pulp and Peels to Dairy Goats on Feed Intake and Milk Yield and Composition. Animals 2020, 10, 194.

Demissie Negash. Study on Compound Animal Feed Demand and Animal Products, Supply, Price and Marketing in Ethiopia. Biomed J Sci & Tech Res 41(3)-2022. BJSTR. MS.ID.006619.

Derbew, B., and J.C. Soon. (2015). Fruit production in Ethiopia: 16-18. Seung Ho, Shin, Korea.

Donkin, D.J., (2007). An Overview of the South African Avocado Industry vol. 1, SouthAfrican Subtropical Growers' Association.

Durak, H.; Aysu, T. (2015). Effect of Pyrolysis Temperature and Catalyst on Production of Bio-Oil and Bio-Char from Avocado Seeds. Res.Chem. Intermed. 41, 8067–8097.

FAOSTAT (2019). Food and agriculture organization of the united nations. http://www.fao.org/faostat/en/#data/QC/visualize.

Fránquez, Pamela; Rodríguez, G.; Lemus, C.; Grageola, F.; Ly, J. (2017). Performance traits and indexes of the intake pattern of fattened pigs with fresh paste of whole avocado Revista Cubana de Ciencia Agrícola, vol. 51, núm. 3, julio-septiembre, 2017, pp. 329-33.6 Instituto de Ciencia Animal La Habana, Cuba.

Freshela Exporters. (2021). Everything You Need to Know About Avocados in Ethiopia -

García-Vargas, M. C., del Mar Contreras, M., & Castro, E. (2020). Avocado-derived biomass as a source of bioenergy and bioproducts. Applied Science, 10(8195), 1–29. https://doi.org/10.3390/app10228195

García-Vargas, M. C., del Contreras, M., Gómez-Cruz, I., Romero-García, J. M., & Castro, E. (2020). Avocado-derived biomass: Chemical composition and antioxidant potential. Proceedings, 4, https://sciforum.net/paper/view/7750.

Galeano-Díaz, J. P., Sánchez-Torres, J. E., Domínguez-Vara, I. A., Morales-Almaraz, E., Rodríguez-Carpena, J. G., Grageola-Nuñez, F., & Nieto-Martinez, G. (2023). Effects on growth performance parameters, carcass traits, meat nutrimental quality and intramuscular fatty acid profile of rabbits fed with diets with avocado waste (Persea americana Mill). Agriculture, 13(3), 549.

González-Fernández, J.J.; Galea, Z.; Álvarez, J.M.; Hormaza, J.I.; López, R. (2015) Evaluation of Composition and Performance of Composts Derived from Guacamole Production Residues. J. Environ. Manage. 2015, 147, 132–139.

Grageola F, Sanginés L, Díaz C, Gómez A, Cervantes M, Lemus C, Ly J. (2010). The effect of breed and dietary level of avocado fat on the N and energy balance in young pigs. Journal of Animal and Feed Science. 19: 37-49.

Grageola, F., Lemus, C., Rodríguez, C., Ponce, J.L. and Ly, J., 2019. Digestibility indices in pigs fattened ad libitum with diets based on cereals and fresh paste of discarded entire avocados. Cuban Journal of Agricultural Science, 53(4).

Hernández-López, S.H.; Rodríguez-Carpena, J.G.; Lemus-Flores, C.; Grageola-Nuñez, F.; Estévez, M. (2016) Avocado Waste for Finishing Pigs: Impact on Muscle Composition and Oxidative Stability during Chilled Storage. Meat Sci. 2016, 116, 186–192.

Hernández-López, S. H., Rodríguez-Carpena, J. G., Lemus-Flores, C., Galindo-García, J., & Estévez, M. (2016). Antioxidant protection of proteins and lipids in processed pork loin chops through feed supplementation with avocado. Journal of food science and technology, 53, 2788-2796.

Jalata, Z. (2021). Current status, potentials and opportunities of avocado production as an alternative crop: The case of Ethiopia: A review. Agricultural Reviews. 1-6. doi: 10.18805/ag.R-179.

Jimenez, P., Garcia, P., Quitral, V., Vasquez, K., Parra-Ruiz, C., Reyes-Farias, M., Garcia-Diaz, D.F., Robert, P., Encina, C. and Soto-Covasich, J., 2021. Pulp, leaf, peel and seed of avocado fruit: A review of bioactive compounds and healthy benefits. Food Reviews International, 37(6), pp.619-655.

Job, B.; Id, L.C.; Fernando, G.; Roberto, V.; Jorge, B. (2021). Effect of Supplementation with Avocado Meal on Lamb Diets on Growth and Carcass Performance. Abanico Vet. 2021, 11, 1–12.

Keire Abdela, Dr. Mamta Brahmbhatt (2023). Review on current status of avocado production in Ethiopia. EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal Volume: 9, Issue: 8..

Leontopoulos, S.; Skenderidis, P.; Petrotos, K.; Giavasis, I. (2021). Corn Silage Supplemented with Pomegranate (Punica granatum) and Avocado (Persea americana) Pulp and Seed Wastes for Improvement of Meat Characteristics in Poultry Production. Molecules 2021, 26, 5901.

Lemus-Avalos, G., Lemus-Flores, C., Bugarín-Prado, J.O., Grageola-Núñez, F., Ayala-Valdovinos, M.A., Duifhuis-Rivera, T., Moo-Huchin, V.M. and Dzib-Cauich, D., 2020. Effect of diets with avocado meal on lipids in muscle, antioxidants and gene expression in finished pigs. Revista bio ciencias, 7.

Lemus-Flores, C., Bugarín Prado, J. O., Grageola Núñez, F., Mejía Martínez, K., Valdivia Bernal, R., & Segura Correa, J. C. (2022). Effects of dietary avocado meal on production performance, carcass traits, muscle fatty acid composition and gene expression of pigs. Veterinaria México OA, 9.

Ly, J., Fránquez, P., Rodríguez, G., Lemus, C., Dominguez, I. A., & Grageola, F. (2021). Note on in vitro digestion of avocado products for pigs. South African Journal of Animal Science, 51(1), 138-141.

Lyu X, Agar OT, Barrow CJ, Dunshea FR, Suleria HAR. (2023). Phenolic Compounds Profiling and Their Antioxidant Capacity in the Peel, Pulp, and Seed of Australian Grown Avocado. Antioxidants (Basel). 2023 Jan 12;12(1):185. doi: 10.3390/antiox12010185. PMID: 36671046; PMCID: PMC9855119.

Marcos, Carlos Navarro, María Dolores Carro, Julia E. Fernández-Yepes, Lesly Arbesu, and Eduarda Molina-Alcaide. (2020). "Utilization of Avocado and Mango Fruit Wastes in Multi-Nutrient Blocks for Goats Feeding: In Vitro Evaluation" Animals 10, no. 12: 2279. https://doi.org/10.3390/ani10122279

Nkosi, B. D., Seshoka, M. L., Fourie, P. J., Kanengoni, A. T., Malebana, I. M. M., & Thomas, R. S. (2020). Dietary enzyme addition on the growth performance and carcass characteristics of pigs fed diets containing avocado oil cake silage. Tropical Animal Health and Production, 52, 2945-2953.

Oelrichs, P. B., Ng, J. C., Seawright, A. A., Ward, A., Schäffeler, L., & Macleod, J. K. (1995). Isolation and identification of a compound from avocado (Persea americana) leaves which causes necrosis of the acinar epithelium of the lactating mammary gland and the myocardium. Natural Toxins, 3(5), 344-349. https://doi.org/doi:10.1002/nt.2620030504

Orabueze, I. C., Babalola, R., Azuonwu, O., Okoko, I. I., & Asare, G. (2021). Evaluation of possible effects of Persea americana seeds on female reproductive hormonal and toxicity profile. Journal of ethnopharmacology, 273, 113870.

Pacheco, A., Rodríguez-Sánchez, D.G., Villarreal-Lara, R., Navarro-Silva, J.M., Senés-Guerrero, C. and Hernández-Brenes, C., 2017. Stability of the antimicrobial activity of acetogenins from avocado seed, under common food processing conditions, against Clostridium sporogenes vegetative cell growth and endospore germination. International Journal of Food Science and Technology, 52(11), pp.2311-2323.

Permal, R., Chang, W. L., Chen, T., Seale, B., Hamid, N., & Kam, R. (2020). Optimising the Spray Drying of Avocado Wastewater and Use of the Powder as a Food Preservative for Preventing Lipid Peroxidation. Foods, 9(9), 1187. https://doi.org/10.3390/foods9091187

Rahul Permal. (2022). Converting Industrial Cold Pressed Avocado Oil Waste into Higher Value Products. A thesis submitted to Auckland University of Technology in partial fulfilment of the requirements for the degree of Doctor of Philosophy (PhD). September 2022.

Rahul Permal, Tim Chia, Giada Arena, Cassandra Fleming, Jack Chen, Tony Chen, Wee Leong Chang, Brent Seale, Nazimah Hamid, Rothman Kam, (2023). Converting avocado seeds into a ready to eat snack and analysing for persin and amygdalin, Food Chemistry, Volume 399, 2023, 134011, ISSN 0308-8146,.

Rodríguez-López, C. E., Hernández-Brenes, C., & de la Garza, R. I. D. (2015). A targeted metabolomics approach to characterize acetogenin profiles in avocado fruit (Persea americana Mill.). RSC advances, 5(128), 106019-106029.

Rodríguez-López, C. E., Hernández-Brenes, C., Treviño, V., & Díaz de la Garza, R. I. (2017). Avocado fruit maturation and ripening: dynamics of aliphatic acetogenins and lipidomic profiles from mesocarp, idioblasts and seed. BMC plant biology, 17, 1-23.

Rodríguez-Sánchez, D.G., Pacheco, A., Villarreal-Lara, R., Ramos-González, M.R., Ramos-Parra, P.A., Granados-Principal, S., Díaz de la Garza, R.I., García-Rivas, G. and Hernández-Brenes, C., 2019. Chemical profile and safety assessment of a food-grade acetogenin-enriched antimicrobial extract from avocado seed. Molecules, 24(13), p.2354.

ROMERO-HUELVA M, Ramírez-Fenosa MA, Planelles-González R, García-Casado P, Molina-Alcaide E. (2017). Can by products replace conventional ingredients in concentrate of dairy goat diet. Journal Dairy Science. 100(6):4500-4512. https://doi.org/10.3168/jds.2016-11766

Runyogote, J., Chacha, M., Ndabikunze, B. and Raymond, J., 2021. Optimized method for processing avocado seeds to improve selected nutrients and functional values. Food Science and Technology Research, 27(1), pp.75-84.

Safrida, Wasilah N and Supriatno P, (2021). Effect of diet combination of avocado Persea americana and pumpkin Cucurbita moschata on Osphronemus gouramy Lac. IOP Conference Series: Earth and Environmental Science 674: 012109 https://doi.org/10.1088/1755-1315/674/1/012109

Sandoval-Contreras, T.; González Chávez, F.; Poonia, A.; Iñiguez-Moreno, M.; Aguirre-Güitrón, L. (2023). Avocado Waste Biorefinery: Towards Sustainable Development. Recycling 2023, 8, 81. https://doi.org/10.3390/recycling8050081

Salazar-López, N. J., Domínguez-Avila, J. A., Yahia, E. M., Belmonte-Herrera, B. H., Wall-Medrano, A., Montalvo-González, E., & González-Aguilar, G. A. (2020). Avocado fruit and by-products as potential sources of bioactive compounds. Food Research International, 138, 109774. https://doi.org/10.1016/j.foodres.2020.109774

Seshoka ML, Fourie PJ, Kanengoni AT, (2020) Dietary inclusion of ensiled avocado oil cake affects growth, nutrient digestion, and carcass characteristics of pigs. Arq Bras Psicol 50:847–854. https://doi.org/10.4314/sajas.v50i6.11

Shamil Alo Sora (2023) Evaluation of Avocado (Persea americana) for Grow thand Yield at Teppi, Southwestern Ethiopia, International Journal of Fruit Science, 23:1, 46-50.

Skenjana A,van Ryssen J B J and van Niekerk W A 2006 In vitro digestibility and in situ degradability of avocado meal and macadamia waste products in sheep. South African Journal of Animal Science.36 (5). https://www.researchgate.net/profile/Jbj-Van-Ryssen/publication/268402806.

Talabi, J. Y., Osukoya, O. A., Ajayi, O. O., & Adegoke, G. O. (2016). Nutritional and antinutritional compositions of processed Avocado (Persea americana Mill) seeds. Asian Journal of Plant Science and Research, 6(2), 6-12.

T. Tesfaye, M. Gibril, B. Sithole, D. Ramjugernath, R. Chavan, V. Chunilall,N. Gounden, (2018). Valorisation of avocado seeds: extraction and characterisation ofstarch for textile applications, Clean Technol. Environ. Policy 20 (9) (2018)2135–2154.

Tugiyanti, E., Iriyanti, N., & Apriyanto, Y. S. (2019). The effect of avocado seed powder (Persea americana Mill.) on the liver and kidney functions and meat quality of culled female quail (Coturnix coturnix japonica). Veterinary world, 12(10), 1608.

Uchenna, U. E., Shori, A. B., & Salihin Baba, A. (2017). Inclusion of avocado (Persea americana) seeds in the diet to improve carbohydrate and lipid metabolism in rats. Revista argentina de endocrinología y metabolismo, 54(3), 140-148.

Yosef T., N. Demise, T. Tadesse and T. Daniel, (2022). Study on the Animal Feed Ingredients and Livestock Product Supply, Price and Market-Related Constraints in Ethiopia. International Journal of Agricultural Research, 17: 102-115.

VAN RYSSEN JBJ, Skenjana A, Van Niekerk WA. (2013). Can avocado meal replace maize meal in broiler diets?. Appied Animal Husbandry and Rural Development. 6: 22-27. https://www.sasas.co.za/AAH&RD/can-avocado-meal-replace-maize-meal-in-broiler-diets/

Velderrain-Rodríguez, G.R.; Quero, J.; Osada, J.; Martín-Belloso, O.; Rodríguez-Yoldi, M.J. (2021). Phenolic-Rich Extracts from Avocado Fruit Residues as Functional Food Ingredients with Antioxidant and Antiproliferative Properties. Biomolecules 2021, 11, 977. https:// doi.org/10.3390/biom11070977

Velázquez-González, F. G., Urquiza-Martínez, M. V., Manhaes-de-Castro, R., Romero-Juárez, P. A., Bedolla-Valdez, Z. I., Ponce-Pérez, J. M., ... & Guzmán-Quevedo, O. (2023). Chronic consumption of avocado seed (Persea americana) promotes a negative energy balance and body weight reduction in high-fat diet exposed mice: Implications for functional foods. Journal of Functional Foods, 108, 105751.

Zuñiga-Martínez, B. S., Domínguez-Avila, J. A., Wall-Medrano, A., Ayala-Zavala, J. F., Hernández-Paredes, J., Salazar-López, N. J., ... & González-Aguilar, G. A. (2021). Avocado paste from industrial byproducts as an unconventional source of bioactive compounds: Characterization, in vitro digestion and in silico interactions of its main phenolics with cholesterol. Journal of Food Measurement and Characterization, 15(6), 5460-5476.

Appendix 1

Questionnaire to collect data on avocado waste per Factory Date:

1. Name of the factory……..
2. Location…….
3. Contact:
    a. Name……
    b. Phone…….. Email…….
4. Main Product (oil, guacamole, …):
5. Extraction/processing method (any heat exposure, solvent, etc..):
6. **Details of waste from the processing plants**
    a. Avocado varieties……
    b. Stage of harvest…….
    c. Residues:

Type	Amount	Seasonality	Frequency	Condition of Residues (fresh, discompose, dry…)	Comments
Full fruit					
Pomace full					
Pomace after extraction					
Seed (stone)					
Peel					
W					

7. Any Seasonal variations, which effect avocado waste production.
    - Season/time of year, Increase in production……Reasons…….
    - Season/time of year, decrease in production……..Reasons……..
8. Current uses of waste at factory ……
9. If waste are disposed by the factory then how do they do it
    a. Dumping…… Frequency:
    b. Through as such on soil…… Frequency:
    c. Through it in rivers/water…… Frequency:
    d. Mixing with spent brewer's grains…… Frequency:
    e. Others……
10. If Storage, then what is the storage capacity for avocado waste ……
11. If storage of waste then What is the Distance of storage from factory……
12. What are the transportation system available to transfer waste from the factory to storage Location and from storage to the potential user…….
13. Per month Housing Cost of an average storage facility ……
14. How much is the cost of transportation per kilometer distance in Ethiopia ……
15. What preservative use by the factory For avocado waste……
16. Any equipment has required for temporary storage/process avocado waste in factory ……
17. If Factory sells avocado waste then what is the unit price……
18. Any possibilities to dry avocado waste on factory side……

SAMPLES INFORMATION

Sample ID	Sample Type (pulp, peel, seed, etc..)	Sample characteristics (e.g. dried or wet)	Weight of sample	Additional information (e.g. any processing of the residue at the plant, etc.)

Appendix 2

Environmental policies and regulations related to waste management in Ethiopia

The 1995 Constitution of the Federal Democratic Republic of Ethiopia (FDRE) serves as the foundation for key principles, encompassing environmental policies. Article 44 of the FDRE emphasizes the right of all people to reside in a healthy and clean environment, while article 92 underscores the government's responsibility to ensure a clean and healthy environment for all Ethiopians.

In line with these constitutional provisions, Ethiopia adopted its Environmental Policy in 1997. The overarching goal of this policy is to enhance the health and quality of life for all Ethiopians, fostering sustainable social and economic development. This is to be achieved through the prudent management of natural, human-made, and cultural resources, ensuring that the environment meets present needs without jeopardizing the ability of future generations to meet their own.

At the national level, the Environmental Protection Agency of Ethiopia assumes the crucial role of ensuring compliance with environmental laws and regulations, aligning activities with policy objectives through the numbers of regulation enumerated in the Annexe 2.

Document	**Relevant content**
Environmental Policy of Ethiopia, 1997	The policy's stated goal is to "improve and enhance the health and quality of life of all Ethiopians and to promote sustainable social and economic development through the sound management and use of natural, human-made and cultural resources and the environment as a whole…" This is done through several sectoral policies as well as some cross-sectoral policies. One sectoral policy specifically addresses waste management through: " The Key Guiding Principles are: […] d. The use of non-renewable resources shall be minimized and where possible their availability extended (e.g., through **recycling**); e. Appropriate and **affordable technologies** which use renewable and non-renewable resources efficiently shall be adopted, adapted, developed, and disseminated;" "3.8. Control of Hazardous Materials and Pollution from Industrial Waste The Policies are: […] m. To promote **waste minimization** processes, including the **efficient recycling** of materials wherever possible;"
Solid Waste Management Proclamation No 513/2007	Article 2 (6) "Solid Waste" means anything that is neither liquid not gas nor is discarded as unwanted. Article 2 (7): "Solid Waste Management" means the collection, transportation, storage, recycling or disposal of solid waste, or the subsequent use of a disposal site that is no longer operational. Article 4 (2): Any person shall obtain a permit from the concerned body of an urban administration prior to his engagement in the collection, transportation, use or disposal of solid waste.
Environmental Protection Organs Establishment Proclamation No 295/2002	Article 2 (1): "Authority" means the Environmental Protection Authority re-established under Article 3 of this proclamation. Article 2 (2): "Competent Agency" means any federal or regional government organ entrusted by law with a responsibility related to the subject specified in the provisions where the term is used.

	Article 2 (4) " Environmental Protection Organs" means the Authority; the Council/the Sectoral and Regional environmental units. and agencies mentioned under Article 111- and 15 of this Proclamation. Article 2 (8 &9): ''Region" means any of those parts of Ethiopia specified as Regions under Article 47(1) of the Constitution of the Federal Democratic Republic of Ethiopia and for the purpose of this Proclamation, includes the Addis Ababa and Dire Dawa Administrations; "Regional Environmental Agency" means any regional government organ entrusted, by that Region, with a responsibility for the protection or regulation of the environment and natural resource.
EIA Proclamation No 299/2002	Article 6(1): no person shall commence any new development activity under any category listed in any directive issued pursuant to this Proclamation ('project') which requires an environmental impact assessment (further specified in art. 5) without an authorization of the Environmental Protection Authority. The Authority or the relevant regional environmental agency may decide that the possible impact of the project is significant and therefore that no EIA shall be carried out (art. 3).
Regulation on Prevention of Industrial Pollution No 159/2008	Article 2 (5) defines industry "existing factory" means a factory that is under operation or a project to which an application to obtain a license to establish a factory has been submitted before or on the date of entry into force of this regulation. Article 2 (6) also defines "pollution" means any condition which is hazardous or potentially hazardous to human health, safety or welfare or to living things created by altering any physical, radioactive, thermal chemical, biological or other property of any part of the environment in contravention of any condition, limitation or restriction made under this Regulation, the relevant environmental standard or under any other relevant law. Article 4 (1) of the regulation indicates: a factory subject to this regulation shall prevent or, if that is not possible, shall minimize the generation of every pollutant to an amount not exceeding the limit set by the relevant environmental standard and dispose of it in an environmental sound manner. Article 4(5) of article 4 also states that: Even if a factory is not subject to the provisions of this regulation, the competent environmental organ may require it to take appropriate measures in order to eliminate any risk that might emanate from its operation.
National Urban Solid Waste Management Strategy, 2017	The Integrated Urban Sanitation and Hygiene Strategy (IUSHS) makes it clear that sanitation and hygiene improvement in urban areas must go beyond the approaches that have served rural sanitation well. Promotion of hygiene awareness, behaviour change, and household investment in toilets are necessary, but must be integrated with a robust chain of services to support improved household sanitation, with effective systems to collect and deliver liquid and solid wastes for safe management, disposal, and possible re-use. Liquid waste service delivery, including safe disposal of human excreta, liquid waste generated by human activities (domestic, industrial, and commercial waste), institutional waste, and safe management of drainage. Solid waste service delivery, including solid waste generated by human activities (domestic, industrial, commercial, and institutional) and safe management of drainage. Promotional and behaviour change including correct hygiene practices, use and management of latrines, uptake of and payment for services, eradication of open defecation, menstrual hygiene management, solid waste management (reduce, reuse, recycle), and other interventions.
Environmental Pollution Control Proclamation No 300/2002	Article 3 (3): Any person engaged in any field of activity which is likely which is to cause pollution or any other environmental hazard shall, when the Authority or the relevant regional environmental agency so decides, install a sound technology that avoids or reduces, to the required minimum, the generation of waste and, when feasible, apply methods for the recycling of waste. Article 3 (4): Any person who causes any pollution shall be required to clean up or pay the cost of cleaning up the polluted environment in such a manner and within

	such a period as shall be determined by the Authority or by the relevant regional environmental agency.
Standards for Industrial Pollution Control, 2013	The purpose of introducing the standards is to prevent significant industrial pollution by indicating standards which must be observed and by indicating pollution limits beyond which the environment would not tolerate. The limit values specified are for emission to the atmosphere, emission to water and noise.

Appendix 3 analysed in this study

Table 17 *Chemical composition (% as DM) of samples in this study.*

	DM	Crude protein	Total Fat Hydrolysis	Crude Fiber	ADL	ADF[a]	NDF	Sugars	Crude ash	Calcium	Phosphorus	Potassium	Magnesium	Starch
AM1	92.42	12.1	37.1	11.9	1.3	47.9	22.5	3.4	21.1	0.1	0.3	3.5	0.2	ND
AM2	88.29	7.8	7.3	10.6	10.7	21.8	29.1	2.7	4.3	0.1	0.1	1.5	0.1	ND[b]
AM3	87.51	12.9	16.0	26.8	24.3	46.6	50.9	0.6	6.9	0.1	0.2	2.2	0.2	ND
AM4	80.86	9.4	1.9	32.1	35.2	54.8	61.5	0.0	5.5	0.2	0.2	2.1	0.1	ND
AM5	87.68	8.1	18.0	20.9	12.6	32.7	32.5	0.8	2.7	0.1	0.1	1.1	0.1	ND
Wet	27.32	10.1	14.6	27.2	32.4	100.3	55.6	<0.5	2.5	0.1	0.1	0.9	0.1	ND
Peels	92.18	6.7	36.3	21.0	15.4	34.3	30.4	4.5	6.6	0.1	0.2	2.0	0.0	ND
Seed	89.14	5.5	3.7	5.1	ND	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	45.1

a there are inconsistencies in fiber fraction results that we cannot explain, including samples with higher ADF than NDF
ND: not analysed in this study
Chloride concentration was lower than the detection limit (<0.06 %) in this study, and it was not analysed in the seed sample

Table 18 *Fatty acid composition (% as total fat).*

	C18:1	C18:2	C18:3	C18:0	C16:0	C15:0	C19:0	C20:1	C6:0	C13:0	C21:0	C16:1	C22:4	C14:0	C18:3 (w3)	C20:0	C20:1	C20:4	C24:0
AM1	60.3	Low	1.1	1.1	13.3	Low	Low	Low	0.3	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
AM2	55.8	14.7	1.5	1.1	21.5	0.2	0.2	0.2	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
AM3	48.8	Low	1.8	Low	23.4	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
AM5	5.8	74.4	Low	Low	1.3	1.5	3.8	Low	Low	0.9	5.6	6.7	Low	Low	Low	Low	Low	Low	Low
YBM	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Wet	48.95	14.18	Low	0.51	22.33	Low	Low	Low	Low	Low	Low	10.22	Low	0.06	1.02	0.08	0.13	0.06	0.07
Peels	Low	45.7	Low	Low	Low	Low	Low	Low	Low	Low	29.9	14.7	9.7	Low	Low	Low	Low	Low	Low

Low: < 0.05

Other fatty acids were Low in all the samples

Table 19 *Antinutritional factors and safety.*

	Aflatoxin-B1 mg/kg	Yeast CFU	Moulds CFU	Tannins mg/kg	Persin mg/kg DW
AM1	ND	ND	ND	ND	924
AM2	ND	ND	ND	ND	338
AM3	ND	ND	ND	ND	658
AM4	< 0.0001	19000	240000	1200	6.4
AM5	< 0.0001	<100	<100	1520	7945
Wet	< 0.0001	3800000	100	4000	4720
Peels	< 0.0001	59000	3000	7180	2649
Seed	ND	ND	ND	ND	3560

ND: test not executed

To explore the potential of nature to improve the quality of life

Wageningen Livestock Research
P.O. Box 338
6700 AH Wageningen
The Netherlands
T +31 (0)317 48 39 53
E info.livestockresearch@wur.nl
www.wur.nl/livestock-research

Wageningen Livestock Research creates science based solutions for a sustainable and profitable livestock sector. Together with our clients, we integrate scientific knowledge and practical experience to develop livestock concepts for future generations.

Wageningen Livestock Research is part of Wageningen University & Research. Together we work on the mission: 'To explore the potential of nature to improve the quality of life'. A staff of 6,500 and 10,000 students from over 100 countries are working worldwide in the domain of healthy food and living environment for governments and the business community-at-large. The strength of Wageningen University & Research lies in its ability to join the forces of specialised research institutes and the university. It also lies in the combined efforts of the various fields of natural and social sciences. This union of expertise leads to scientific breakthroughs that can quickly be put into practice and be incorporated into education. This is the Wageningen Approach.