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The use of industrial hemp (*Cannabis sativa*) on farm animal's productivity, health and reproductive performance: a review

H. T. H. Muedi[A], T. C. Kujoana[B], K. Shai[B], M. Mabelebele[B] and N. A. Sebola[B,*]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
N. A. Sebola
Department of Agriculture and Animal Health, College of Agriculture and Environmental Sciences, University of South Africa, Florida 1710, South Africa
Email: sebolan@unisa.ac.za

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ABSTRACT

Global food insecurity is mostly the result of human-animal competition for food, as well as recent population growth, erratic weather patterns and environmental shocks. Therefore, maximising the production of animal proteins can reduce the competition between demand and consumption. Hence, the current review aimed at outlining the use of hemp on the production, health and reproductive performances of farm animals. The data used in this review were accessed using Google Scholar, Science Direct, ResearchGate and the directory of open-access journals. It was found that industrial hemp, particularly its derivatives such as hemp-seed meal and oil, has gained attention for its potential benefits in animal nutrition and health. The impact of hemp on farm animals, their productivity, health and reproductive performance, is an area of ongoing research. Our findings on the assessment of the nutritional benefits of hemp to livestock have shown hemp to be a great nutritional source to livestock because, hemp-seed cake, a byproduct of hemp oil extraction, is rich in essential and non-essential amino acids, fibre, and healthy fats, including omega-3 and omega-6 fatty acids. When incorporated into animal feed, it can contribute to a balanced diet, potentially improving overall health and productivity. Furthermore, the health benefits may be due to the fatty acid profile in hemp that is known to have positive effects on animal reproduction (optimal fertility and gestation) and health, including anti-inflammatory properties, which could benefit conditions related to inflammation. Additionally, hemp contains compounds such as cannabinoids and terpenes that might offer therapeutic effects, although the effects of these compounds in animals are still being studied. In conclusion, there is limited direct research on hemp's effect on reproductive performance in farm animals. Hence, more research is necessitated.

Keywords: animal nutrition, animal reproduction, cannabinoids, health benefits, hempseed meal, industrial hemp, nutritional benefits, reproductive performance.

Introduction

Animal production is of great importance due to its provision of complete proteins to meet the increasing demand of an on-growing global population (World Health Organization (WHO) 2003; Henchion *et al.* 2017). Maximal animal production requires proper animal nutrition, health and reproduction, which can be met through proper animal feeding of high-quality feed (Wu 2014; Zhang *et al.* 2021). More research has recently focused on the exploration of plant materials and by-products known for their vast nutritional traits as possible feed supplements because feed companies face a shortage of primary proteins and energy ingredients and also synthetic metabolites due to a variety of factors such as high ingredient costs and climate change (Alhotan 2021). The *Cannabis sativa* L. plant (industrial hemp) is widely available and known for its ability to withstand harsh climatic conditions and has lately been found and reintroduced into the agricultural grounds (Ahmad *et al.* 2016). The hemp plant is reportedly high in natural primary and secondary metabolites through its varied parts such as seed, leaf, stem, roots and flowers (Galasso *et al.* 2016), which can be used to enhance feed quality and, alternatively, be used for its pharmacological purposes so as to improve animal productivity, health and reproduction performances (Russo *et al.* 2008; Rodriguez-Leyva and Pierce 2010; Andre *et al.* 2016). Phytochemicals, amino acids, phenolic acids, fatty acids, lignans, terpenoids and protein hydrolysates produced from hemp can combat the effects of oxidative stress in a way that improves animal health and reproduction (Girgih *et al.* 2014; Teh *et al.* 2014). Furthermore, the hemp plant produces oil through its seed, which is high in polyunsaturated fatty acids that are very important in animal nutrition due to the probable transfer of linoleic fatty acids from feed to food (Berquin *et al.* 2008; Rossi *et al.* 2010; Duan *et al.* 2014). Also, hempseed oil is a major source of fat-soluble vitamins and concentrated energy twice the quantity of carbohydrates and proteins (Hadrová *et al.* 2021). It is then used for household consumption and slightly as a supplement in animal feed to reduce feed powderiness and enhance the absorption of vitamins as well as feed acceptability to improve energy requirements (Alagawany *et al.* 2019). However, some studies have shown negative impacts of hemp on animals' reproductive performance due to the presence of a cannabinoid called delta-9 tetrahydrocannabinol, which is categorised as an antinutrient concentrated mainly in leaves (Whan *et al.* 2006; Fonseca and Rebelo 2022), although leaves are the primary source of polyphenols, antioxidants and dietary minerals. As a result, continuous cultivation of crops such as hemp for its seed and leaf production should be maintained globally, because seeds are the primary source of proteins, B vitamins, fibre and dietary fat for animal feeding (Kleinhenz *et al.* 2020), so as to aid in improving animal production, health and reproductive performances (Kala *et al.* 2006). This will help reach the maximum production of animal proteins to meet the current high global demand. Therefore, the objectives of this review are to (1) provide an overview of description, historical production and potential uses of hemp, (2) summarise nutritional and chemical characteristics of hemp, (3) describe the effects of hemp supplementation on the growth, reproduction and health of farm animals, and (4) discuss potential applications for hemp use in the medical and feed industries.

Methods

Literature search strategy

A literature search was conducted to identify peer-reviewed and published papers, starting from the year 1991 to 2023, on the basis of the nutritional capacity, and medicinal benefits of industrial hemp and its probable use in farm animals to enhance productivity and reproduction performances. Published articles were accessed using Google Scholar, Science Direct, ResearchGate and the directory of open-access journals. The keywords used in the search process included 'industrial hemp, farm animals, hemp seeds, hemp leaves, hemp stem, hemp flowers, medicinal benefits, nutritional value, animal performance, animal health and animal reproduction'. In addition, citations included in articles were used to find other relevant articles or documents.

Selection and sorting criteria (inclusion and exclusion)

Searched articles were evaluated and sorted according to the following criteria: (1) year of publication; (2) the document being published in a peer-reviewed journal or book; (3) the subject matching our focal point; and (4) the article or part thereof being about medicinal properties of industrial hemp. The use of these search criteria generated 18 600 relevant articles. Furthermore, full versions of these articles were read, evaluated and sorted using the inclusion and exclusion criteria. Non-English written and published studies, those studies that did not address the effects of hemp-based meal on animal productivity and reproduction and studies on human-based research were excluded. The included articles met the following requirements: (1) the use of hemp in animal feed, (2) the health benefits of hemp, (3) the nutritional composition of hemp, (4) the effect of hemp on animal reproduction performance and (5) the effect of hemp on growth and meat quality. Only 154 articles met the selection criteria.

History of industrial hemp production

Industrial hemp (*C. sativa*) has been grown and used for many years in Europe, Asia, and North America (Rupasinghe *et al.* 2020). According to Rosenthal (1994), it is thought that the hemp plant was first cultivated and used in modern Asia and subsequently spread from there throughout the Middle Ages and into the end of the Age of Sail and, therefore, it was a vital crop in many European nations (Carus and Sarmento 2016). Furthermore, when hemp began to spread across continents over time, Miller (1991) demonstrated that this plant was first imported to North America in 1606. Following World War Two, the production and cultivation of industrial hemp plants became unstoppable, virtually disappearing from Western European countries challenged by the production of industrial fabrics and cotton, metallic material for navigation ropes, and Manila and Juta for packaging during long maritime trips (Giupponi *et al.* 2020). Therefore, hemp farming was then fully restored in the early 1990s and for a long time it was a crop produced on ~10 000–15 000 ha of land (Carus *et al.* 2013). Then the cultivation reached about 40 000 ha in 2018, reaching the greatest record levels in Europe (Ciupan *et al.* 2018). In contrast, the Canadian Opium and Narcotics Act restricted and labelled hemp cultivation as illegal, while the United States Marijuana Tax Act of 1938 placed cultivation under the control of the United States Treasury Department, requiring specific documentation to grow hemp (Cherney and Small 2016). As a result, to be legally considered hemp, the plant needed to contain less psychoactive ingredient delta-9-tetrahydrocannabinol (approximately 0.2% or 0.3%) by dry weight and, therefore, became largely planted for fibre-seed production, thus limiting its use as an oil source (Small 2015). Hemp has a unique character and the capacity to adapt to varied climatic variations, resulting in increased yields (Finnan and Styles 2013; Amaducci *et al.* 2015). This plant is naturally dioecious, which is wind-pollinated, with male plants dying after producing millions of pollen grains (Faux *et al.* 2013). In temperate regions, the hemp plant is farmed as a source of bast fibre, the same as plants such as flax, kenaf, roselle and jute (Manaia *et al.* 2019). *C. sativa* and *C. indica* appear to be closely related since they have characteristics such as having palm-split leaves and producing flowers of different sexes (Kuddus *et al.* 2013). A mature hemp plant seldom produces only few branches with wide, fat, bladed leaves such as those of *C. indica* (Andre *et al.* 2010). However, current research focuses on the effects of hemp on the medical industry and oil production rather than its cultivation. As a result of its legalisation in many states, further studies are urged to report on its present production and distribution status.

The potential uses of industrial hemp fibre and seeds

The *C. sativa* plant belonging to the Cannabaceae family was previously harvested at an early growth stage primarily for its fibre. Therefore, with time, hemp became cultivated for agricultural production purposes with the inclusion of its fibre then seeds and its by-products including oil, seed cake and hurds. Therefore, this plant has been identified through its lower concentrations of tetrahydrocannabinol, which are normally less than 1% (Johnson 2013). It is, therefore, a common psychoactive herb that is used both recreationally and medicinally. Furthermore, this plant has been used (Fig. 1) for its fibres to make textile rope, clothing, shoes, food, paper, bioplastic, insulation and biofuel since ancient times before it was appreciated for pharmacological uses (Dariš *et al.* 2019; Rupasinghe *et al.* 2020). Because of the rising use of this plant, several governments around the world banned it, including its by-products, in 1973, resulting in a reduction in economic performance (Aryal and Adhikari 2019). However, the legalisation of hemp began slowly in a few countries for research and significant medical capacity (Kalant 2001). As a result, the plant gained popularity and was further legalised in many countries. Also, it was then employed as a source of fibre, protein and other essential nutrients through its seed in animal nutrition, particularly broilers (Pirie 1987), although animals such as dairy cows, laying hens and sheep did not perform well in some areas that include reproductive performances. Through the production of fibre, oil and pharmaceuticals, hemp has the

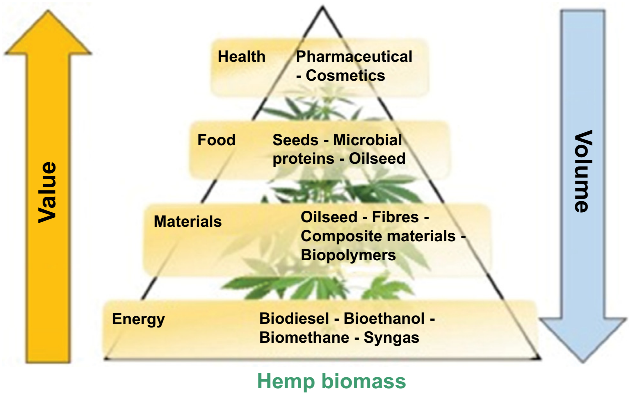

Fig. 1. Breakdown of the use of hemp. Source: Moscariello *et al.* (2021).

potential to create a sizeable market. These plant fibres have an outer ring of long phloem fibres and an interior ring of small xylem fibres (Fike 2016). The potential and production of the hemp plant as animal feed have received less attention due to the significant focus that many scientific studies have placed on the toxicity of hemp on human health and reproductive functions.

Hemp leaves and flowers

Previously, hemp leaves (Fig. 2*a*) and flowers (Fig. 2*b*) were considered waste; nevertheless, they were later consumed in the form of beer and smoked for recreational purposes and to enhance appetite (Shrestha 1992), and further used for medicinal and spiritual purposes due to the cannabinoid chemicals they contain (Bhatia *et al.* 2014). Moreover, the literature continued to show that an Italian company (CANNPA) then cultivated hemp for the commercial purpose of its leaves; however, the chemical composition of hemp leaves and flowers was reported to be useless and should be removed, hence supporting the valorisation of locally produced plants and their use as pharmaceuticals and cosmetic treatments (De Vita *et al.* 2022). Furthermore, the dried hemp leaves and petals were used in culinary preparations such as herbal tea, whereby this tea was typically consumed for calming nerves, much like any other herbal tea and, hence, added flavour (Torres 1983). The leaves can be further processed into juice, making them a rich source of full plant protein, omega-3 and omega-6 fatty acids, fibre and minerals with medical value. As a result, evidence suggests that hemp as a complete protein source can enhance kidney health and be beneficial to those with chronic renal illnesses (Giugliano *et al.* 2006; Iftikhar *et al.* 2021). Furthermore, the antioxidant chemicals found in the leaves of this plant are well known to be used for their anti-ageing properties as well as their capacity to protect against the development of many diseases (Rehman *et al.* 2021). However, there has been little or no research on the utilisation of hemp leaves and flowers in

Fig. 2. Hemp (*a*) leaves and (*b*) flowers. Sources: Omare *et al.* (2021); Malabadi *et al.* (2023).

enhancing the production of farm animals. As a result, more research into the use of hemp leaf-meal on the enhancement of farm animal production performance is required to determine whether the leaves can be of great benefit to the animals or not as they are reported to be less utilised.

Hemp seed and oil

Hemp is widely grown to produce seeds (Fig. 3*a*), which are then utilised partly as human food and animal feed, and mainly for the extraction of oil (Fig. 3*b*) which, like any other oilseed, is economically significant (Mirpoor *et al.* 2021; Nevara *et al.* 2023). Throughout the history of hemp-seed production, it has been recorded as a source of food ingested raw, cooked, and roasted, and this seed can be further processed into a slurry and used for baking and beverages such as hemp milk and tisanes (medicinal drink) (Kynes 2016). Cherney and Small (2016) discussed this seed as one of the main grains of ancient China used as human food and animal feed for more than 3000 years. Furthermore, in harvesting periods, hemp seeds are picked as soon as they begin to break off the indeterminate inflorescence, at which point over 70% of the seeds are ripe (Elias *et al.* 2020). Furthermore, they produce more oil than any other fibre crop and have a specific fatty acid profile (Xu *et al.* 2021). Because of their great nutritional content, hemp seeds can be eaten raw or crushed into hemp oil, which is to be used for human and animal consumption (Aluko 2017). The extracted oil is normally used for flavouring and as a fragrance additive (Bertoli *et al.* 2010). The oil turns out to be a great source of fat-soluble provitamin A and vitamin E where the provitamin A can simply be converted into vitamin A in an animal and human body. They contribute positively to animal and human growth, meat and milk production, metabolism and development. This was seen in study by Šťastník *et al.* (2019) and Skřivan *et al.* (2020) where there was an improved meat quality and bone morphology in broilers, while Neijat *et al.* (2014) showed the reduction of liver damage in bovan white. In addition, this vitamin further provides body energy and the formation of body cells (McDowell 2012). As a provitamin A, β-carotene acts as an antioxidant and protects hemp oil from oxidation. Furthermore, this form of vitamin can be utilised as a feed supplement to improve sperm quality by shielding the sperm cell from oxidative stress caused by an imbalance of reactive oxygen species. By scavenging free radicals, it can also help reduce disease outbreaks (Callaway 2004).

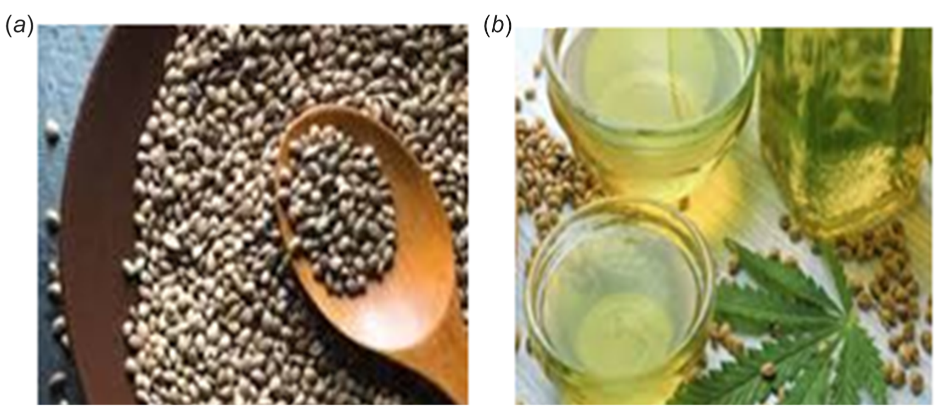

Fig. 3. Hemp (*a*) seeds and (*b*) oil. Sources: Chatterjee and Gandhi (2022); Bjarnadottir (2018).

However, because there are not enough studies on the use of hemp seed and oil as supplemental ingredients in animal diets, especially on their effects on the reproductive performance, there is a strong need for researchers to delve deeper into the use of these plant's seed and oil supplements, which are high in proteins, fatty acids, amino acids, minerals, and medicinal properties on the overall animal health and production. This will be useful in meeting some of the objectives of the sustainable development goals (SDGs) of 2050.

Hemp stem

The *C. sativa* plant was previously grown for its stems (Fig. 4*a*), which were then processed into rope and yarn. The inner layer of the stem was commonly used to produce fuel, building materials and animal bedding, while the outer layer of the bast fibres is stripped off and processed into various by-products such as rope, paper and mat (Visković *et al.* 2023). Furthermore, the stem contains significant amounts of cellulose and low concentrations of lignin through its barks, which also contain a variable proportion of lower-value secondary bast fibre that is more important as a raw material for paper than is the core (Kozlowski *et al.* 2005). Hemp fibres (Figs 4*b*) can also be utilised to strengthen enlarged bio-based polymers (e.g. starch-based) in the food-packaging sector (Amaducci *et al.* 2015). Cannabis stems offer practically all the needed nutrients to the animal body, including carbohydrates, water, minerals, and trace amounts of calcium, sodium, and potassium (Farinon *et al.* 2020). However, the use of hemp stem-based meals has not been reported yet; this might be because stems are poor in protein and high in fibre and lignin, and also, due to their hardiness, they require processing before consumption. As a result, researchers are urged to experiment more with hemp stem-based diets in animal production to utilise the above-mentioned compounds in animal feeds.

Nutritional and medicinal properties of the hemp plant

Through its seeds, leaves, roots and flowers, hemp is abundant with nutritional and medicinal properties (Adesina *et al.* 2020). The hemp plant contains a variety of essential nutrients, which include dietary crude proteins, lipids, crude fibre, vitamins and minerals. As a result, House *et al.* (2010) showed whole hempseed to have about 24.0 ± 2.1% crude protein, 30.4 ± 2.7% crude fat, 32.1 ± 2.5%, dietary fibre, 4.8 ± 0.7% ash and 94.1 ± 2.0% dry matter. Furthermore, Leonard *et al.* (2020) also presented the nutritional composition of the whole hemp seed, which contained approximately 35.5% crude oil, 30% crude protein, 25% carbohydrate, 27.6% crude fibre, and 5.6% ash, whereas Vonapartis *et al.* (2015) presented the seed chemical composition of various industrial hemp cultivars, with Finola having the highest compositions, including 93.72% dry matter, 280 g/kg crude protein, 306 g/kg oil, 58 g/kg ash and 332 g/kg neutral detergent fibre. The seed protein composition contains high concentrations of arginine and glutamic acid as well as sulfur-containing amino acids (Callaway 2004). However, when processed into a seed cake, it contains the highest crude protein content of 40.7% and crude fibre of 30.5% (House *et al.* 2010). Furthermore, various species of hemp seed tend to be rich in minerals such as calcium (144–955 mg), magnesium (237–694 mg), potassium (463–2821), iron (1133–2400), manganese (63–110 mg) and zinc (42–94 mg) (Mihoc *et al.* 2012). Among medicinal plants, hemp is high in bioactive compounds that have been used significantly for health and consumption purposes. It constitutes phytochemicals, cannabinoids, Δ^9-tetrahydrocannabinol terpenoids, flavonoids (cannflavin and kaempferol), terpenes (limonene and α-pinene), phytocannabinoids (tetrahydrocannabinolic acid, cannabidiolic acid, cannabichromenic acid and cannabigerolic acid), polyphenols (caffeic acid, quercetin and luteolin) and steroids, making it a complex herbal medicine (Pollastro *et al.* 2018).

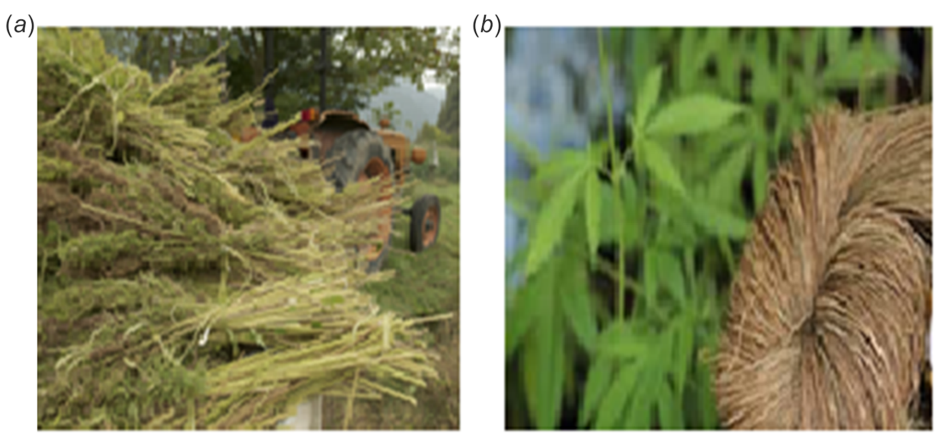

Fig. 4. Hemp (*a*) stems and (*b*) fibres. Source: Crônier *et al.* (2005).

Approximately 80% of hemp-seed oil is composed of nutrients, making it a potentially valuable animal feed ingredient; therefore, the oil is abundant with polyunsaturated fatty acids between 75% and 80%, including 17–19% linoleic acid (LA, C18;2 *n*-6) and about 60% α-linolenic acid (ALA, C18:3 *n*-3) (Parker *et al.* 2003; Mierliţă 2018). Also, hemp hulls, dehulled seeds and whole hemp seeds and their by-products such as seed cake are great constituents of essential amino acids (Callaway 2004). Tables 1, 2, 3, and 4 present phenolic compounds of different parts of the hemp plant,

Table 1. Phenolic compounds of different parts of hemp plant.

Hemp-plant part	Composition					References
	TPC (mg/g)	N-trans caffeoyltyramine	Cannflavin A	Cannflavin B	TFC	
Leaves	0.89	ND	0.28 mg/g	0.11 mg/g	2.54 mg/100 mg	Flores-Sanchez and Verpoorte (2008); Allegrone *et al.* (2017)
Defatted seeds	7.8	0.8 mg/g	1.6 mg/g	ND	ND	Irakli *et al.* (2019)
Inflorescences	125.12	36.1 mg/kg	72.9 mg/kg	98.8 mg/kg	6.3 mg/g	Ferrante *et al.* (2019); Izzo *et al.* (2020); Palmieri *et al.* (2020)
Seeds	72.7	ND	ND	ND	109 mg/g	Wang and Weller (2006); Teh *et al.* (2014); Vonapartis *et al.* (2015)
Seed meal	7.33	0.287 mg/g	ND	0.153 mg/g	0.27 mg/g	Pojić *et al.* (2014)

TPC, total phenolic compounds; TFC, total flavonoid compounds; ND, not detected.

Table 2. Amino acid profiling of various products of hemp seed.

Hemp-plant part	Composition (%)								
	Asp	Thr	Ser	Glu	Pro	Gly	Ala	Cys	Val
Whole seeds	2.25	0.89	1.08	3.55	1.00	1.00	0.97	0.35	1.07
Dehulled seeds	3.86	1.37	1.83	6.68	2.04	1.78	1.71	0.68	1.94
Seed meal	3.04	1.09	1.35	4.76	1.33	1.27	1.05	0.62	1.52
Hemp hulls	1.23	0.47	0.56	1.76	1.23	0.52	0.51	0.81	0.91

Source: House *et al.* (2010).
ASP, aspartic; Thr, threonine; Ser, serine; Glu, glutamic acid; Pro, proline; Gly, glycine; Ala, alanine; Cys, cysteine; Val, valine.

Table 3. Fatty acids of various hemp-seed products.

Hemp-plant part	Composition (%)						References
	Palmatic acid	Stearic acid	Oleic acid	Linoleic acid	α-linolenic acid	γ-linolenic acid	
Roasted seeds	5.96	2.56	16.12	58.52	16.44	–	Babiker *et al.* (2021)
Hemp-seed oil	6.61	2.67	15.88	55.48	16.51	0.82	Kiralan *et al.* (2010)
Hemp seeds	6.20	2.10	9.50	56.10	22.40	3.70	Mierliţă (2018)
Seed cake	9.30	3.80	13.10	52.50	19.10	2.20	Mierliţă (2018)

Table 4. The cannabinoid content of different hemp components.

Hemp-plant part	Composition (μg/g)					
	Can	Δ^9-Tet	Can A	Can B	Can G	Can C
Leaf	31.0	186.0	36 920.0	3347.0	293.0	4041.0
Stalk	4.0	573.0	1705.0	132.0	28.0	500.0
Flower	27.0	31.0	32 900.0	3502.0	230.0	2916.0
Seed head	11.0	664.0	3184.0	262.0	23.0	411.0

Source: Kleinhenz *et al.* (2020).
Can, cannabinol; Δ^9-Tet, Δ^9-Tetrahydrocannabino; Can A, cannabidiolic acid; Can B, annabidiol; Can G, cannabigerol; Can C, cannabichromenic.

amino acids profiling of various products of hemp seed, fatty acids of various hemp-seed products and cannabinoid concentrations in various parts of hemp respectively.

Effect of hemp on the production (growth, meat quality and milk) performance of farm animals

The inclusion of hemp meal in animal diets has recently gained popularity in animal nutrition. Most research has confirmed the usefulness of hemp in enhancing animal production performance by measuring overall growth performance by using several criteria such as daily weight increase, feed intake, and feed conversion ratio (Khan *et al.* 2010; Mahmoudi *et al.* 2015). Dietary supplementation of hemp-based diets in poultry did affect growth performance (Skřivan *et al.* 2020). As reported by Khan *et al.* (2010), broiler chickens fed a hemp seed-based diet had enhanced bodyweight gain, feed intake, and feed conversion ratio at various inclusion levels (0%, 5%, 10%, and 20%). At the 20% inclusion level, broiler chickens gained more weight (2087.2 ± 10.25 g), owing to a greater feed conversion ratio (1.95 ± 0.032), but consumed less feed than did broilers fed the control diet (5014.4 ± 6.3 g). However, at a 5% inclusion level, broilers showed a higher feed intake (4506.9 ± 91.9 g) than those in all diets with hemp inclusion. Even though hemp seed contains the tetrahydrocannabinol compound, which stimulates appetite, the availability of cannabinoid receptor antagonists eventually reduces feed intake (Kleinhenz *et al.* 2020), demonstrating that hemp can be easily consumed, digested and converted into the body, thus improving the growth performance of farm animals such as broiler chickens. It is well known that oil as a by-product of hemp seed can improve bodyweight gain also in broilers, cockerels and ducks because it enhances feed utilisation (Khan *et al.* 2010) through the availability of polyunsaturated fatty acids such as omega-3 and omega-6, making it the most perfectly balanced oil (Simopoulos 2002). Despite the fact that it contains antinutrient substances such as cannabinoids and tannins, growth performance in some animal species such as sheep, dairy cows and laying hens may not be influenced either positively or negatively (Silversides and LefranÇois 2005; Lardy *et al.* 2009).

With enhanced growth performance, particularly in the feed conversion ratio seen in broilers, ducks, and cockerels, the inclusion of hemp-based meals in animal diets may improve meat quality in terms of flesh colour and sensory attributes (Farinon *et al.* 2020). Both hemp seeds and oil contain *n*-3 fatty acids, which have the potential to increase the quality of poultry meat (Palmquist 2009). Juodka *et al.* (2022) showed that adding hemp-seed cake to a duck's diet enhanced the *n*-3 and *n*-6 polyunsaturated fatty acids in the breast and leg muscles. Also, Šťastník *et al.* (2019) and Skřivan *et al.* (2020) found that at 5% and 15% inclusion levels of hemp-seed cake, there was a change in meat colour and odour, thus improving meat quality at 30, 40, and 50 g/kg inclusion levels of hemp seed. The nutritional effects of hemp-based meals, which are rich in polyunsaturated fatty acids, amino acids, vitamins, and minerals, have a good influence on broiler, duck and cockerel production performance (Khan *et al.* 2010). Hemp seed-based meal has been further shown to have the potential to enhance milk production and quality due to its nutritional content (Farinon *et al.* 2020); however, high cannabinoid concentrations in dairy cattle diet result in tired and unstable cows with a lower feed intake, resulting in decreased milk output (Kanabus *et al.* 2021). Even the milk produced from these cows contains cannabinoids such as delta9-tetrahydrocannabinol, which in turn will be bad for human consumption because it may result in the production of serious adverse effects that include tachycardia and anxiety (Wagner *et al.* 2022). However, as reported by Karlsson *et al.* (2010), at a 143 g/kg inclusion level, hemp meal enhanced milk yield in dairy cattle. Also, Cozma *et al.* (2015) and Mierlita *et al.* (2023) showed that the inclusion of hempseed meal enhances goat milk fat content, polyunsaturated fatty acid profile, lipophilic antioxidant content and total antioxidant capacity, whereas Mierliță (2018) reported the oxidative stability in sheep milk following the incorporation of hemp seed and hemp-seed cake (60.85 and 33.72 mg/100 g DM respectively) in a diet containing tocopherols. To the best of our knowledge, there has been less documentation on the effect of hemp-based meals on the milk production of farm animals. As a result, we urge more research to be conducted to supplement the existing literature.

Effect of hemp on the health performance of farm animals

The health of an animal, as well as the provision of high-quality feed, can ensure maximum production performance in terms of growth, meat quality and milk production (Madeira *et al.* 2017). Although growth-promoter supplements have been used in animal diets for decades to improve health, they have been shown to have some adverse effects on meat quality that compromise human health (Kocher 2005). As a result, hemp is being employed as an alternative to the present growth promoters, some synthetic medicines and protein ingredients due to its superior nutritional attributes and medicinal benefits (Naeem *et al.* 2023). Few studies have shown the medicinal properties of hemp to be responsible for the alleviation of stress (Wheeler and Fields 1993), enhance immunity (Zhu *et al.* 1997) and suppress tumorous cells in animal bodies (Blázquez *et al.* 2003). Furthermore, these properties are also known for antimicrobial, antivirus, antipyretic, antiparasitic and insecticidal activities (Roy and Tandon 1997; Novak *et al.* 2001). As a result, Khan *et al.* (2010) concluded that a combination of these features may have improved the health performance of broiler hens fed a diet containing

20% hemp. Furthermore, hemp has also been used as a broad-spectrum application for pain management, anti-inflammatory activities and antioxidative stress modulation (Bolognini et al. 2010). This was reinforced by Neijat et al. (2014), who demonstrated that hemp seed (10%, 20%, and 30%) and hemp-seed oil (4.5% and 9.0%) contain gamma-glutamyl transferase, which lowers liver damage in bovine white birds. However, with these positive benefits, hemp also has some negative effects because it contains oligosaccharides that cause stomach discomfort and gas, which are generally present in soyabeans and are utilised in traditional medicine to cure flatulence (Mahmoudi et al. 2015). Kanabus et al. (2021) indeed presented some of the negative effects of hemp in dairy cows where high cannabinoid concentrations in hemp seed induced changes in cow behaviour and compromised health with slow breathing and cardiac rate. To the best of our knowledge, there has been less research on the harmful impacts of hemp on the health performance of farm animals. As a result, more research into the detrimental impacts of hemp on farm animal's health is required.

Effect of hemp on reproductive performance of farm animals

Excellent reproductive performance leads to maximum animal production and therefore maximises their by-products such as milk, meat and eggs, which are regarded as animal proteins (Garry 2004). However, reproductive performance of farm animals is affected generally by various factors such as nutrition, health and, last, by climate and environmental conditions, with health and nutrition being the main factors (Roche et al. 2000). Industrial hemp contains a variety of critical nutrients including both essential and non-essential amino acids, polyunsaturated fatty acids and secondary metabolites such as antioxidants that are necessary for the development and generation of both male and female gametes as well as reproductive hormones (Henkel et al. 2018). However, reports have shown that the inclusion of hemp in animal diets has positive effects in terms of growth performance and affects the overall animal reproductive system negatively, resulting in reproductive disorders (Cohen et al. 2019). This is due to the high secretion of cannabinoids and delta9-tetrahydrocannabinol chemicals, which further hinders the spermatogenesis processes, reducing the concentrations of hypothalamic, pituitary and sex hormones, including the morphological structure of sperm cells (Dalterio et al. 1984; Thompson 1993; Pacey et al. 2014). High cannabinoid chemical concentration in hemp inhibits reproductive performance, especially reducing the libido in males (Payne et al. 2019). This critically employs researchers to carefully perform useful chemical characterisation of this plant before its inclusion in animal diets, so as to have a clear overview of the amount of nutritional and anti-nutritional compounds, and secondary metabolites that are available (Apprey et al. 2018). Hemp contains compounds such as antioxidants and polyunsaturated fatty acids, which can fight against the harm caused by oxidative stress, enhance semen quality and combat some reproductive disorders (Skoracka et al. 2020). Therefore, a hemp-seed cake-based diet fed to laying hens resulted in less or no effect on the egg-laying capacity and egg quality of hens (Silversides and LefranÇois 2005). Furthermore, evidence reveals that increasing emphasis has been placed on the use of hempseed and its by-products as animal feed to supplement the missing vital nutrients and, so, to improve total animal reproduction and the overall output (Montero et al. 2023), while less emphasis has been placed on the use of hemp leaves and other parts. This could be because of the high quantities of the Δ^9-tetrahydrocannabinol molecule, which has been shown to decrease other aspects of male reproductive activities (Maccarrone et al. 2021). Hence, it is advisable for farmers to not provide feed that enhances the production performance of animals but, at the same time, inhibits reproductive efficiencies. As a result, more research on varied inclusion levels and dosage of hemp meal and extracts composed of leaves, flowers and other underutilised hemp parts is required. This will boost the poor-quality feed challenges faced by animal producers in the future.

Future utilisation of hemp in medical and feed industries

Due to containing toxic substances, which tend to endanger both animal and human health and reproductive abilities, hemp has historically been prohibited from being publicly grown and used in many countries since it was domesticated (Small and Marcus 2002; Fox et al. 2013). Additionally, because of the restrictions placed on the cultivation and use of hemp, its potential as a source of feed for animals was disregarded (Mikos 2009; Thompson et al. 2014). As a result, only licence holders were allowed to cultivate the plant for specific purposes, such as the production of fibre (Struik et al. 2000; Bismarck et al. 2005; Small 2015). However, research showed the opposite, and usage of hemp was made lawful in a variety of activities, since it was shown to be a potential therapeutic plant that included vital nutrients, minerals and secondary metabolites (Passari et al. 2017). As a result, cannabinoids, terpenes, and flavonoids, which are abundant in hemp vegetative and reproductive organs, can be employed in therapeutic applications or as bio-pesticides against insects or fungi, and are among the high-value metabolites being recovered from hemp (Amaducci et al. 2015). With the current legalisation amendment for hemp, Canada, Europe, the United States, Africa, and other regions of the world continued to support research into and usage of this versatile plant (Simiyu et al. 2022). As a result, output surged in 2018 because of the Cannabis Act SC 2018, c. 16. Current industrial discoveries on hemp applications have shown that its growth has fewer

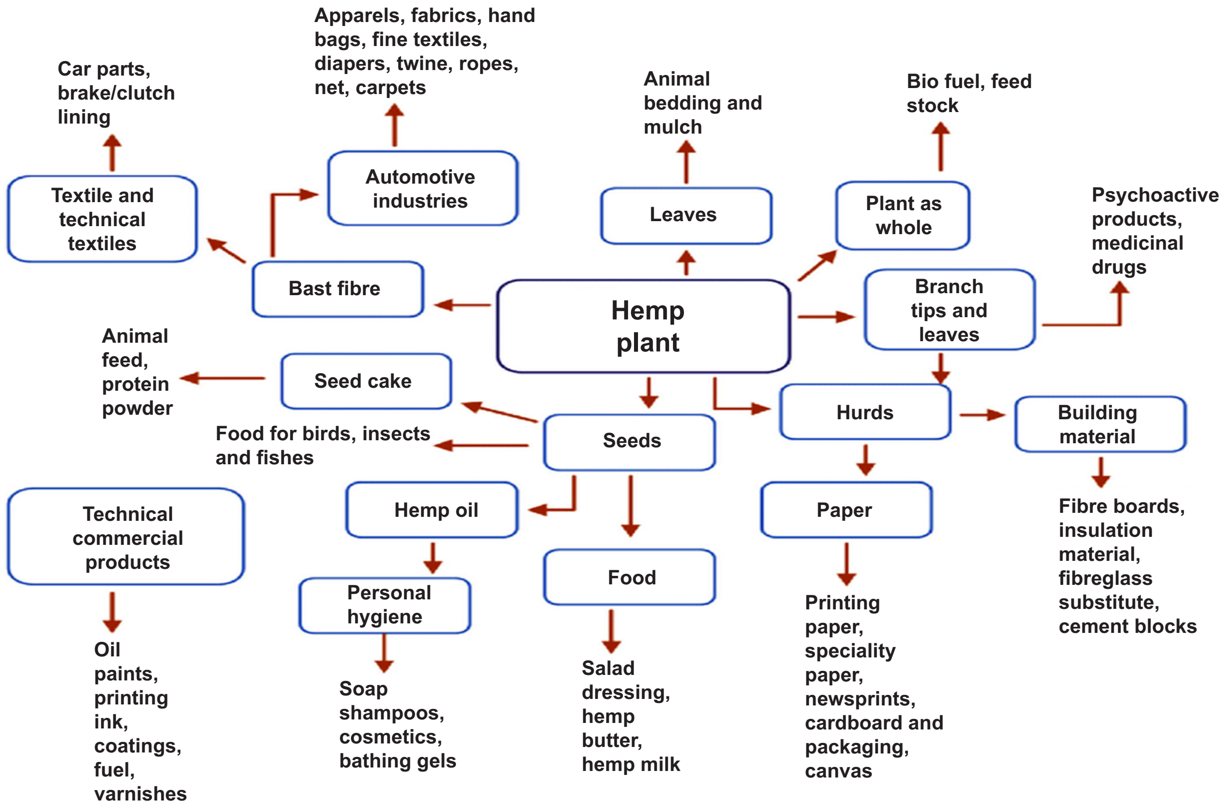

Fig. 5. Demonstration on the future uses of the industrial hemp plant. Source: Karche and Singh (2019).

environmental implications because it grows quickly and outperforms weeds, requiring less or no pesticides and improving the physical and chemical fertility of the soil (Sorrentino 2021). Many countries throughout the world are interested in hemp farming because of its capacity to adapt easily to diverse climatic conditions, hence lessening climate change and desertification. As a result, studies have revealed that hemp can cut greenhouse gases, with the 2030 target of the European Union anticipating a 40% reduction from 1990 (Sorrentino 2021; Madden *et al.* 2022). Hemp leaves and flowers produce a great composition of secondary metabolites and these are used as tea, whereas its seeds produce highly nutritious oil and protein that could be used by the agricultural business to make flour, milk, pasta and pastries (Sorrentino 2021; Kujoana *et al.* 2023). Its stem produces two types of fibre (the external part of the stem), which stand to be used as feedstock for the manufacturing of various bio-based consumer products (Andre *et al.* 2016; Musio *et al.* 2018). Compared with soybean, hemp seed can be used as an alternative due to its incredible crude protein composition and this plant is locally and readily available because it can survive in any environment; thus, it is cost-effective (Callaway and Pate 2009). According to Jiang *et al.* (2016), hemp is a kind of cannabis that generates lower levels of psychoactive tetrahydrocannabinol (THC), making it possible to grow in high-temperate regions for fibre production and later for food production. Consuming a high concentration of this chemical causes narcotic effects; however, the cannabidiol chemical it contains is not a narcotic and cannot result in any kind of drug high (Lowitt 2020). Fig. 5 clearly outlines the future uses of the hemp plant (Karche and Singh 2019).

Conclusions

The utilisation of industrial hemp, particularly its derivatives such as hemp-seed meal and oil, shows promising potential in positively affecting farm animal productivity, health, and reproductive performance. The nutritional profile of hemp, being rich in essential fatty acids, proteins, and other bioactive compounds, suggests possible benefits when incorporated into animal diets. These benefits might include improved nutrition, potential anti-inflammatory effects, and support for overall animal health. However, further research is necessary to determine optimal inclusion levels, assess potential interactions, and ensure compliance with regulatory standards to harness the full potential of industrial hemp while safeguarding animal welfare.

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Author affiliations

[A]Agricultural Research Services, Northwest Department of Agriculture and Rural Development, 114 Chris Hani Street, Potchefstroom 2520, South Africa.

[B]Department of Agriculture and Animal Health, College of Agriculture and Environmental Sciences, University of South Africa, Florida 1710, South Africa.