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The nutritional benefits of maize-soybean rotational systems in the North-Western Free State, South Africa

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Abstract

Background Malnutrition is one of the major health concerns, particularly in the developing and under-developed world. In South Africa, maize is produced as a staple food and is the primary food for most of the country's population. The North-Western Free State which forms part of the Nala municipality in the Lejweleputswa district of South Africa is a main producer of the country's maize. However, the area is known for its sandy soil which contains little organic material, silt and clay. Maize in this area is normally grown in monoculture but with a focus on sustainable agriculture has recently incorporated soybean. As a means of fighting malnutrition, the objective of this study was to determine the influence that soybean incorporation as a rotation crop has on the nutritional value of maize.

Methods A trial was conducted on the farm Christinasrus in the North-Western Free State to compare the nutritional value of monoculture maize and maize in rotation with soybean over three consecutive seasons. Maize kernel samples were taken each season and its nutritional properties analyzed. Subsequent data were further analyzed using statistical analysis.

Results Results showed that there was a seasonal effect on all nutritional properties with a general decrease in nutritional values in wetter years. Cropping systems had an effect on fibre content, with increased values observed in maize after soybean. In addition, there was a significant interaction between season and cropping systems on the total digestible nutritional value, with maize after soybean being more nutritious in wetter seasons.

Conclusion Results suggest that maize in cropping systems with soybean has potential to be more nutritious while the soybean in the cropping system can act as a protein-rich companion, providing a more balanced diet for human consumption, thereby fighting malnutrition.

Keywords Crop rotation, Maize, Nutrition, Soybean, Sustainable agriculture

Background

Malnutrition is a major concern in the developing and under-developed world, mainly due to poverty, unemployment, and lack of access to health food [1]. In 2018, about 59% of South African children lived below the poverty line, depriving them nutritionally [2]. Maize (*Zea Mays*) is the country's staple food, especially among low-income groups, as it is affordable and accessible making it their primary form of nutritional intake [3].

Maize kernels are the edible part of the plant used for processing and consumption [4, 5]. The outermost layer of a maize kernel, the pericarp (seed coat) is made up of the fibres: Hemicellulose, cellulose and lignin [4]. Crude fibre, which is a measure traditionally associated with animal nutrition, is indigestible and remains as a food

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residue after digestion [6]. Crude fibre is also found in the endosperm and embryo (germ) but in much lower quantities [4]. The total dietary fibre, which is more commonly used in relation to human nutrition, is similar to crude fibre in that it is not digested but rather passes through the body intact to help food move through the digestive tract and assist in nutrient absorption [6]. Sufficient intake of dietary fibre improves health and reduces the risk of heart disease, type 2 diabetes and colon cancer [6]. The endosperm is the largest section of the maize kernel, mostly made up of starch which is the primary carbohydrate constituent of a kernel [4]. Other carbohydrates include small amounts of sugars such as glucose, sucrose and fructose [7]. Digestion of carbohydrates together with fats provides a source of energy [8, 9]. Energy can be stored in fats and used when calorie intake is insufficient to meet demand [8].

The endosperm also has the majority of the crude protein, which includes the nitrogen content [4, 10]. Protein is found in the embryo (germ) in higher concentrations than the endosperm but of less quantity [4]. Generally maize has a low protein content (about 8%) which limits its nutritional value [11, 12]. The low protein content is because of the lack of essential amino acids, lysine and tryptophan, which are essential for building and maintaining the body [11]. These amino acids contribute to the production of enzymes and antibodies which are vital for normal body functions [13].

There have been advancements in the development of quality protein maize as well as fortification by adding vitamins and minerals [4, 14]. However, maize on its own remains an unbalanced diet [3]. The nutritional deficiencies caused by a lack of dietary diversity can be alleviated by soybean (*Glycine max*) [14]. Soybean not only acts as a protein-rich companion to maize when included in a daily diet but also improves soil health and crop productivity when included in sustainable agricultural systems [15, 16]. The objective of this study was to determine if there is a rotational effect on the nutritional value of maize.

Methods

Study location and design

The study was conducted in the North-Western Free State, South Africa. This area forms part of what is known as South Africa's 'maize quadrangle' (Fig. 1). The general climate conditions of the North-Western Free State include hot summers, mild winters and an annual rainfall of approximately 500 mm per year [17]. The overall soil health of the area is poor (Haney Soil Health Scores averaging about 4) which can be attributed to the sandy soils that are made up of very little organic material, silt

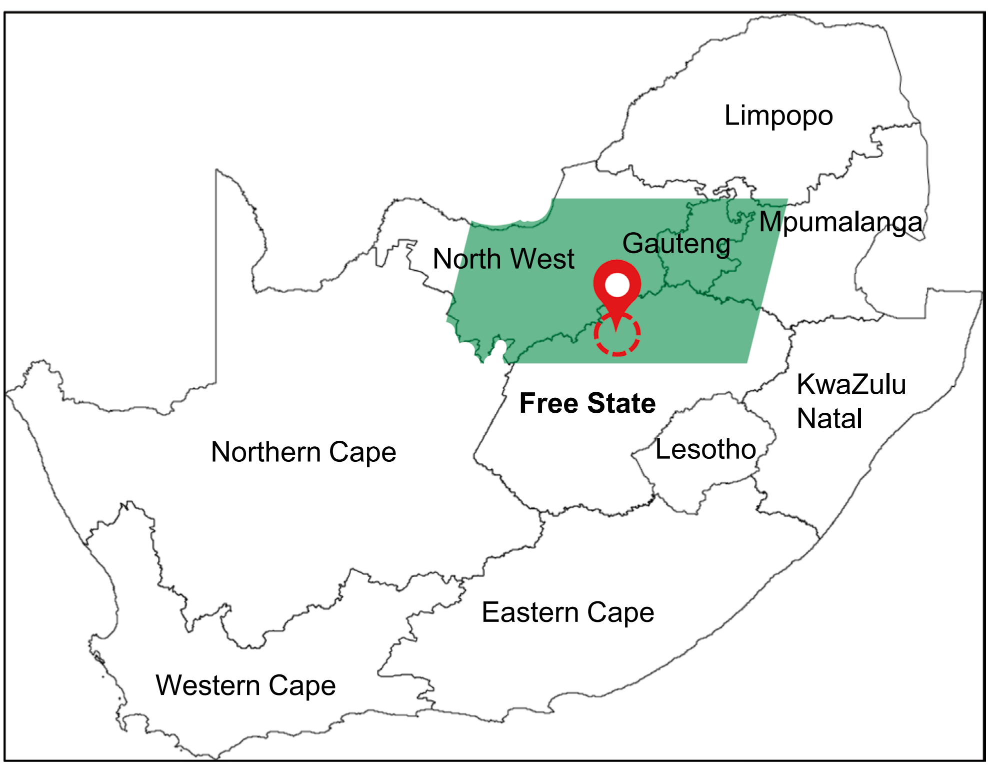

Fig. 1 Site of sample collection (North-Western Free State, South Africa)

and clay [18, 19]. Only about 1–2% of the soil is made up of silt while the clay content in the A-horizon is normally less than 10%, and less than 15% in the B-horizon [17]. The soil has a relatively high rate of water filtration however, the layer of clay at a depth of 1.5 m–2 m prevents water drainage, often forming a temporary water table which is utilized by crops [18]. The ability of the North-Western Free State soils to effectively store rainwater is a major contributing factor to the high maize production in the area [18].

A trial comparing three different crop rotation systems (maize-cover crop-soybean (MCS), maize-soybean-maize (MS) and maize-maize-soybean (MMS)) with monoculture maize (MM) were established on the farm Christinasrus near the agricultural towns of Bothaville and Wesselsbron in the Lejweleputswa district of the North-Western Free State. The MMS system was further identified as MMS1 and MMS2 to distinguish between the first (MMS1) and second (MMS2) season of maize. A randomized complete block design with three replicates was used for the trial layout. There were 27 plots in total, of which each were 80×24.4 m in size. Rotational systems were assigned to plots and each crop within each system, representing a different stage in each season to be able to distinguish between seasonal and rotational effects. The trial was monitored for three consecutive seasons: 2020/2021, 2021/2022 and 2022/2023.

The trial plots were prepared through the practise of rip-on-row at a depth of 0.75 m in August or September of each season. Trials were planted in the preceding December, post preplant fertilization. Maize varieties included DKC75-65 in the 2020/2021 and 2021/2022 season and DKC76-77 in the 2022/2023 season. Soybean varieties included P64T39 in season 2020/2021 and PAN1644 in season 2021/2022 and 2022/2023. The cover crop mixture was made up of 60% grasses and 40% legumes. Maize plots were additionally fertilized at planting and top-dressed. This resulted in a total of 116–135 kg ha^{-1} nitrogen, 12–16 kg ha^{-1} phosphorous and 5–9 kg ha^{-1} potassium being added seasonally. Soybean and cover crops received preplant and during planting fertilizer. Weeds in maize and soybean plots were controlled using Glyphosate. All field actions were done with commercial equipment.

A favourable rainfall season was experienced during the 2020/2021 season, a total of 689 mm was measured at the trial location from September 2020 to May 2021. The 2021/2022 season had a very wet start compared to the previous season, with 309 mm of rain being measured in December 2021 alone and a seasonal total of 922 mm. The third season saw a more widespread rainfall season with 700 mm measured between September 2022 and May 2023.

Sample collection

Maize kernels (grain) were hand collected after maturity for nutritional analysis from all maize plots during each season. Two samples were randomly collected per maize plot. Samples from the same rotation system were combined to give a holistic sample per rotation system. Nutritional analysis included measuring moisture, crude fibre, total dietary fibre, crude fat, crude protein, ash, total carbohydrates, energy and TDN value. Analysis was conducted by a service provider using South African National Accreditation System (SANAS) accredited methods, and values were calculated using standard operating procedures (SOP) [12].

Data analysis

Data were cleaned and prepared for the Statistical Package for Soil Sciences (SPSS) version 29, where it was further analyzed using descriptive and inferential statistics. The rotational system variable was transformed into a dichotomous cropping system variable to compare the nutritional values in maize after maize and in maize after soybean. Two-way analysis of variance (ANOVA) was run to determine if there was a statistically significant interaction effect of cropping system and season on crude fibre, total dietary fibre, crude fat, crude protein, total carbohydrates, energy and TDN value, respectively. Assumption testing included testing for outliers, normal distribution, and homogeneity of variances. Statistical significance was accepted at $p \leq 0.05$.

Results

Table 1 illustrates the mean measurements and ANOVA results of nutritional parameters for each cropping system in each season. Most nutritional parameters were affected by season. There were two dominant seasonal trends, the first (and most common) being a decrease in measured values from season one (2020/2021) to season two (2021/2022), with an increased value in the third season (2022/2023). This was the case for crude fibre, dietary fibre and crude fat (Fig. 2). Fibre contents improved up to 13% over the duration of the study. The second seasonal trend was the opposite to the first trend, with an increase in measured values from season one (2020/2021) to season two (2021/2022) and a decreased value in the third season (2022/2023). This was seen in measured values of crude protein and total carbohydrates however, the overall depletion was less than 5% (Fig. 3.).

The effect of the cropping systems was seen in the fibre content of maize. Maize after soybean had 4–8% higher amounts of crude and dietary fibre respectively. In addition, there was an interactive effect between season and cropping systems for the energy value and

Table 1 Mean measurements and ANOVA results of nutritional parameters for each cropping system in each season

Nutritional parameter	Cropping system		Season 1 (2020/2021)	Season 2 (2021/2022)	Season 3 (2022/2023)		ANOVA results					
							Cropping system		Season		Interaction	
							F	*p*-value	*F*	*p*-value	*F*	*p*-value
						Mean						
Crude fibre ($g\ 100\ g^{-1}$)	Maize after maize		1.65	1.50	1.90	**1.68**	21.67	< 0.001	75.96	< 0.001	1.49	0.24
	Maize after soybean		1.83	1.57	2.07	**1.82**						
		Mean	**1.74**	**1.54**	**1.99**							
Dietary fibre ($g\ 100\ g^{-1}$)	Maize after maize		8.60	8,00	9.60	**8.73**	9.76	0.003	72.48	< 0.001	0.33	0.72
	Maize after soybean		8.90	8.43	9.83	**9.05**						
		Mean	**8.75**	**8.22**	**9.72**							
Crude fat ($g\ 100\ g^{-1}$)	Maize after maize		3.35	3.10	3.45	**3.30**	1.89	0.18	126.34	< 0.001	2.96	0.06
	Maize after soybean		3.30	3.13	3.40	**3.28**						
		Mean	**3.33**	**3.12**	**3.43**							
Crude protein ($g\ 100\ g^{-1}$)	Maize after maize		6.31	6.85	6.03	**6.40**	0.96	0.33	17.26	< 0.001	0.50	0.61
	Maize after soybean		6.30	6.61	5.98	**6.30**						
		Mean	**6.31**	**6.73**	**6.01**							
Total carbohydrates ($g\ 100\ g^{-1}$)	Maize after maize		66.90	67.60	67.15	**67.22**	0.84	0.37	3.82	0.03	1.03	0.37
	Maize after soybean		66.10	68.07	66.33	**66.83**						
		Mean	**66.50**	**67.84**	**66.74**							
Energy value (kJ $100\ g^{-1}$)	Maize after maize		1301.00	1313.00	1304.00	**1306.00**	0.53	0.47	14.55	< 0.001	10.31	< 0.001
	Maize after soybean		1318.00	1317.33	1289.00	**1308.11**						
		Mean	**1309.50**	**1315.17**	**1296.50**							
TDN (%)	Maize after maize		89.40	89.45	90.50	**89.78**	3.81	0.06	0.70	0.51	6.69	0.003
	Maize after soybean		90.70	90.20	89.80	**90.23**						
		Mean	**90.05**	**89.83**	**90.15**							

Bold values are mean

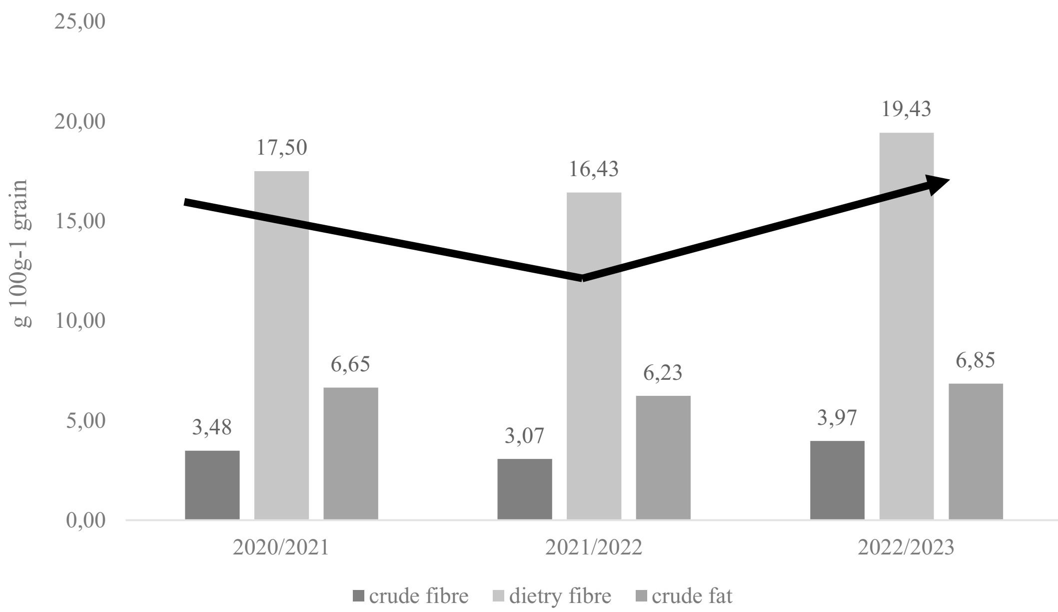

Fig. 2 Seasonal trend for crude fibre, dietary fibre and crude fat

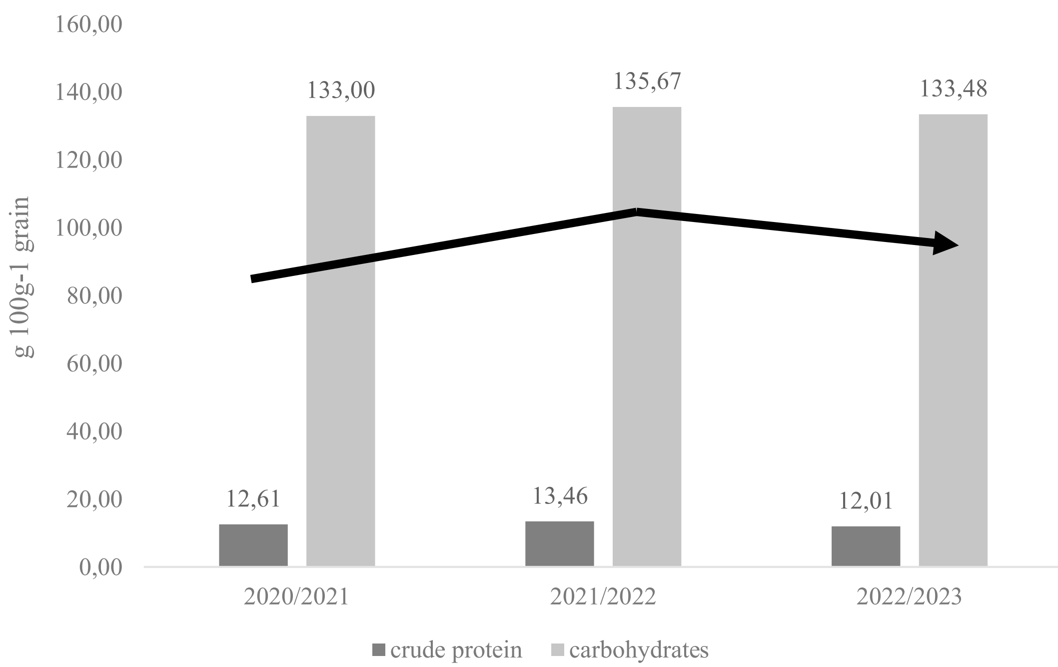

Fig. 3 Seasonal trend for crude protein and carbohydrates

TDN. The energy value and TDN were proportional to each other with maize after soybean having a 1–2% higher TDN in the wetter 2021/2022 season, while maize after maize was 1% more nutritious in the drier 2022/2023 season. These results had a large effect size, $\eta = 0.26$ [19].

Discussion

Nutritional factors of maize are often neglected because there is no premium provided by markets for maize with superior nutritional value [8]. The nutritional analysis of maize kernels in this study showed the importance of maize as an essential food crop. Maize contained valuable amounts of fibre, fat, carbohydrates and energy. The lower amount of protein observed is a common characteristic of maize [3], but could have been worsened by the sandy soil, as well as its poor soil health [20]. A study [21] found that maize grown in physically and chemically unfavourable soil resulted in an inferior protein content in maize.

The composition of maize kernels was influenced by season and has been highlighted in many publications [22–24]. During the wetter second season (2021/2022) most nutritional parameters declined, however, they were able to recover again in the more favourable third season (2022/2023). The wet conditions caused the maize to undergo abiotic stress, weakening its metabolic processes which reduced nutrient assimilation [23]. However, despite the decline in nutritional parameters, the TDN of maize after soybean was higher than maize after maize in the wetter seasons, this could be due to the interactive affect observed between season and cropping system.

The inclusion of soybean into cropping systems with maize resulted in higher amounts of crude and dietary fibre. Costa et al. [16] found similar results in their study where legume-modified rotations improved nutritional output of cereals. A higher fibre content could assist in the fight against malnutrition as it improves overall health [6]. Despite the protein content of maize not being influenced by the inclusion of soybean, actual protein intake can be increased by introducing soybean directly into a daily diet. Soybean contains 35–40% protein and nine essential amino acids, resulting in a more nutritious, balanced diet when combined with maize [25, 26].

Conclusions

The production of maize grown in cropping systems with soybean should be promoted as a sustainable practise to fight malnutrition. Results from this study suggest that maize in cropping systems with soybean improves the fibre content of maize while the soybean in the system can act as a protein-rich companion, providing a more nutritious, balanced diet for human consumption. Furthermore, maize after soybean had a better TDN than maize after maize in wetter conditions. It is recommended that similar studies be carried out in different soil types and under different environmental conditions to gain further insight into the effects of crop rotation on maize nutrition.

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Author contributions
MD analyzed and interpreted the data as well as wrote the manuscript. AN did the study design and trial layout as well as proofread the manuscript. JV assisted with administration duties.

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Availability of data and materials
The datasets used and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval and consent to participate
University of the Free State (UFS-ESD2022/0118).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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