https://doi.org/10.17221/84/2023-CJAS

Dietary levels of soluble and insoluble fibre sources for young slow-growing broilers

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Citation: Oliveira N.R., Santos F.R., Sousa Silva M.R., Rissato I.S., Roque G.C., Silva C.M., Barros H.S.S., Silva N.F., Minafra C.S., Araúju Neto F.R. (2024): Dietary levels of soluble and insoluble fibre sources for young slow-growing broilers. Czech J. Anim. Sci., 69: 139–154.

Abstract: This study aimed to evaluate the effects of dietary levels of soluble and insoluble fibre on the performance and digestive development of slow-growing broilers during the starter period. A total of 400 one-day-old Isa Label™ male chicks were used that were distributed in a completely randomized factorial design 2 × 2 + 1 (inclusion of 2% or 4% of corncobs as a source of insoluble fibre IF and citrus pulp as a source of soluble fibre (SF); and a control treatment) with eight replicates of 10 birds each. The addition of IF to diets improved the weight gain and feed conversion of broilers at 7 and 21 days of age. Both fibre sources added to diets resulted in higher relative weights of proventriculus + gizzard, liver, small and large intestine. The diets containing an SF source presented positive effects on the duodenal mucosa. In addition, positive effects on the caecal villus to crypt ratio were observed in broilers fed diets containing different types of fibre. It is concluded that dietary inclusion of IF up to 4% maintains the performance, nutrient metabolism and improves the development of the proventriculus + gizzard in slow-growing broilers. However, for improving the morphological and histomorphological parameters of slow-growing broilers in the starter phase the addition of SF sources is recommended.

Keywords: backyard poultry; citrus pulp; corncobs; growth performance; gut morphology; intestinal histomorphometry

Organic and free-range chicken production for eggs and meat stands out among alternative poultry production systems. The use of slow-growing strains, popularly known as improved backyard poultry, is strongly recommended due to the intrinsic demands of these systems. Slow-growing strains have delayed growth (Santos et al. 2005) and lower nutritional requirements compared to conventional strains.

Previous studies have shown that slow-growing chickens also have distinct gastrointestinal characteristics and nutrient utilization compared to traditional broiler chickens (Santos et al. 2014, 2015). Therefore, slow-growing strains require an adequate nutritional management plan to meet their requirements.

Little is known about the effects of dietary fibre sources on slow-growing broilers. Experiments car-

We thank FAPEG (Research Support Foundation of the State of Goiás) for funding the scholarship for the first author.

https://doi.org/10.17221/84/2023-CJAS

ried out with conventional broilers have shown that fibre acts as a diluent in diets and can reduce broiler performance (Hetland et al. 2004). However, recent studies have demonstrated the beneficial effects of fibre on animal metabolism and behaviour and its potential to improve nutrient digestibility, depending on the physicochemical properties of the fibrous fractions, inclusion level, fibre source and broiler's age (Gonzalez-Alvarado et al. 2010; Mateos et al. 2012; Jimenez-Moreno et al. 2016; Jimenez-Moreno et al. 2019; Tejeda and Kim 2021).

Sources of soluble fibre, such as pectin from citrus pulp, may increase the viscosity of the digesta in the gastrointestinal tract and inhibit the absorption of nutrients. On the other hand, Sadeghi et al. (2015) reported that broilers fed diets containing high levels of soluble fibre (30 g/kg) showed intestinal hypertrophy and improved humoral immunity. Likewise, the dietary inclusion of sources of insoluble fibre, such as corncobs, can have a positive effect on the development and activity of the gizzard by increasing maceration and food retention in the organ (Hetland et al. 2003). As a result, it increases the contact surface area between nutrients and gastric secretions, which extends the action of digestive enzymes and improves the digestibility and absorption of nutrients (Mateos et al. 2012).

The fibre can affect the metabolism of birds in different ways depending on the type and content of fibre (soluble and insoluble), age of the birds and nutritional quality of the non-starch polysaccharides (NSPs). They also affect the development and morphological integrity of the intestinal mucosa (Tejeda and Kim 2021). Slow-growing broilers reared under backyard poultry production systems must have access to a grazing area, i.e., they should have access to high-fibre feeds from 28 days onwards (ABNT 2015).

Given the beneficial effects that moderate levels of fibre can have on the development of the digestive system and, consequently, the performance of conventional chickens, it is likely that feeding different sources of fibre (soluble or insoluble) during the starter period makes young animals more physiologically prepared for consumption of fibrous foods. Moreover, it would also contribute to reductions in production costs and improvements in the welfare of slow-growing birds.

This study aimed to evaluate the effects of different dietary levels of soluble and insoluble fibre on performance, carcass and cut yields, digestive organ development, nutrient utilization and intestinal histomorphometry of slow-growing broilers during the starter period.

MATERIAL AND METHODS

Animals and housing

The experiment was carried out at the Federal Institute of Education, Science and Technology of Goiás – Campus Rio Verde, Goiás, using 400 one-day-old Isa Label male chicks with an initial weight of 41 ± 0.68 g. The experiment was approved by the Ethics Committee on Animal Use (CEUA/IFGoiano) under Protocol No. 8966250118/2018.

The experiment lasted for 35 days. The animals were allotted to a completely randomized 2 × 2 + 1 factorial design (soluble and insoluble fibre; dietary inclusion of 2% and 4% of fibre and a control treatment), with eight replicates of 10 birds per plot. Corncobs were used as a source of insoluble fibre (IF) and citrus pulp as a source of soluble fibre (SF). The control (low-fibre) diet was formulated based on corn and soybean meal and the medium- and high-fibre diets were added 2% and 4% of the test fibre sources, respectively.

The chicks were kept in a battery-cage system composed of eight galvanized wire cages with dimensions of 0.90 m × 0.60 m × 0.40 m, equipped with trough-type feeders and drinkers, 70 W halogen lamps for heating and metal trays for excreta collection. Each cage was considered as a plot. The chicks remained under constant lighting (natural and artificial), and the ambient temperature during the experimental period averaged 26 °C ± 3.06.

Water and feed were provided *ad libitum* throughout the experimental period. The mortality rates were 1.25% in animals fed the control diet and diets containing 2% IF, 2% SF, whereas they reached 2.5% in birds fed diets containing 4% citrus pulp.

Experimental diets

The diets were formulated on an isoenergetic and iso-nutrient basis (Table 1) to meet the nutritional requirements of medium-growth broilers according to Rostagno et al. (2011).

The nutritional composition of the experimental diets (Table 1) and of the citrus pulp and corncobs

https://doi.org/10.17221/84/2023-CJAS

Table 1. Ingredients and composition of experimental diets from 1 to 35 days of age

Ingredient (g/kg)	Control	Soluble fibre		Insoluble fibre	
		2%	4%	2%	4%
Corn grain (7.86%)	655	620	584	616	582
Soybean meal (45%)	254	257	260	260	260
Gluten (60%)	45.0	45.0	45.0	45.0	45.0
Citrus pulp	0	20.0	40.0	0	0
Corncob	0	0	0	20.0	40.0
Dicalcium phosphate	15.6	15.7	15.8	15.6	15.8
Limestone	9.91	9.61	9.60	9.52	9.41
Mineral/vitamin suplement[1]	7.50	7.50	7.50	7.50	7.50
Salt	4.66	4.67	4.67	4.66	4.66
L-Lysine HCL	4.27	4.28	4.26	4.16	4.23
DL-Methionine	2.46	2.53	2.61	2.50	2.60
L-Threonine	0.840	0.910	0.980	0.860	0.960
Soya oil	0	12.5	25.0	13.8	25.1
L-Tryptophan	0	0	0	0	1.81
Calculated nutritional levels (g/kg)					
Metabolizable energy (MJ/kg)	12.4	12.4	12.4	12.4	12.4
Crude protein	200	200	200	200	200
Digestible lysine	11.4	11.4	11.4	11.4	11.4
Digestible methionine + cystine	8.22	8.22	8.22	8.22	8.22
Digestible Threonine	7.42	7.42	7.42	7.42	7.42
Digestible Tryptophan	1.94	1.94	1.94	1.94	1.94
Calcium	8.60	8.60	8.60	8.60	8.60
Phosphorus available	3.84	3.84	3.84	3.84	3.84
Sodium	2.10	2.10	2.10	2.10	2.10
NDF	110.0	113.40	115.40	123.80	135.90
ADF	39.80	42.40	44.90	47.11	54.10
Determined nutritional levels (g/kg)					
Dry matter	91.88	91.84	91.72	91.61	92.09
Crude protein	197.97	189.42	186.41	204.21	199.59
Ash	47.77	54.79	48.58	48.52	45.23
NDF	109.45	114.35	118.77	121.95	134.25
ADF	46.85	48.99	51.10	53.69	60.25
Cellusose[2]	18.79	21.24	23.69	24.35	29.70
Hemicellulose[3]	62.60	65.36	67.67	68.27	70.00
Lignin	28.07	27.55	27.41	29.34	30.57

[1]Vitamin/mineral supplement (per kg of diet): manganese 93.3 mg; zinc 73.3 mg; copper 3.3 mg; iron 9.5 mg; iodine 160 mg; selenium 45 mg; retinol 1 000 000 IU; cholecalciferol 200 000 IU; tocopherol 2 000 IU; menadione 3.2 mg; thiamine 2.0 mg; riboflavin 6.4 mg; niacin 40 mg; pantothenic acid 20 mg; pyridoxine 3 mg; cyanocobalamin 24 mg; ascorbic acid 10.6 mg; folic acid 1.00 mg; biotin 13.3 mg; choline 45.2 mg; methionine 295 mg; [2]Cellulose = ADF − lignin; [3]Hemicellulose = NDF − ADF

ADF = acid detergent fibre; NDF = neutral detergent fibre

https://doi.org/10.17221/84/2023-CJAS

in this study was analysed for moisture, ash, nitrogen (N), ether extract, neutral detergent fibre, acid detergent fibre, and acid detergent lignin according to standard procedures described by Detmann et al. (2012). The analysed nutritional composition of the citrus pulp and corncobs was as follows: dry matter content 91.62% and 95.30%, crude protein 7.29% and 2.59%, mineral matter 3.04% and 1.93%, ether extract 2.12% and 0.46%, neutral detergent fibre 18.28% and 80.29%, acid detergent fibre 12.37% and 39.45%, and lignin 2.35% and 16.2%, respectively.

Broiler performance

The following performance [feed intake (FI), feed conversion (FC), weight gain (WG)] parameters were evaluated weekly until 35 days of age. The feed conversion was adjusted based on the date and number of deaths.

At 35 days of age, one bird per treatment and replicate was slaughtered by cervical dislocation. The carcass yield and cut yields (breast, thigh, drumstick) and percentage of abdominal fat were calculated.

Assessment of nutrient utilization

The coefficients of apparent metabolisability of dry matter, crude protein and neutral detergent fibre of the experimental diets were determined by total excreta collection from 10 to 13 days and 32 to 35 days of chicken age. Feed intake and total excreta output were measured.

The cages were equipped with aluminium trays underneath, in which a plastic bag was placed to collect the excreta at 8 a.m. and 3 p.m. every day. Subsequently, the collected excreta were packed in plastic bags, identified and frozen for further analysis of the dry matter, crude protein and neutral detergent fibre levels according to Silva and Queiroz (2002).

Morphometry of the digestive tract and intestinal histomorphometry

One bird per replicate with live weight close to the treatment average was weekly slaughtered by cervical dislocation and eviscerated to assess the morphometry of the digestive tract and intestinal histomorphometry.

To assess the gastrointestinal morphometry, the measurements were taken of total gastro-intestinal length (cm and weights) and weights of proventriculus + gizzard, small intestine, large intestine, liver and pancreas. The relative weights of digestive organs were calculated by dividing the carcass weight by the live weight of birds.

Duodenal and caecal fragments of approximately 4.0-cm length were carefully collected for histomorphometric analysis. The segments were washed under distilled water, identified, preserved in a buffered formaldehyde solution for 24 h, and then kept in 70% alcohol until slide preparation.

Histological images were captured at 4 × magnification using an optical microscope and image analysis software (Image-Pro Plus®). The studied variables were villus height (VH), crypt depth (CD) (30 readings per slide of each animal) and villus to crypt ratio (V/C).

Data analysis

The normality of the data was tested using the Shapiro-Wilk test. A boxplot was used to check for outliers; then, the data were subjected to analysis of variance.

Orthogonal contrasts were used to compare the effects of different fibre sources and levels by the *F*-test at a significance level of 5%. Data from qualitative factors (fibre sources and levels) were compared by Tukey's test at a significance level of 5%. The data were evaluated using the R-Project free software.

RESULTS

Performance, carcass yield and cut yields

Overall, birds fed diets containing different fibre sources and levels had similar performance to those fed the control diet. However, feed intake at 7 days of age and feed conversion at 21 days of age were worse in birds fed diets containing different fibre sources and levels (Table 2).

The addition of an IF source improved the average weight of broilers by 8.3% at 7 days of age and feed conversion by 10.2% at 21 days of age.

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Table 2. Feed intake (FI), weight gain (WG), average weight (AW) and feed conversion (FC) of slow-growing broilers fed diets containing different levels of soluble fibre (SF) and insoluble fibre (IF) sources at 1 to 35 days of age

Control vs treatment	Control	Soluble		Insoluble		SEM	Fibre sources		Fibre levels		*P*-value			
		2%	4%	2%	4%		SF	IF	2%	4%				
7 days											C × F	SF	LF	S × L
FI (g)	120	110	110	110	110	8	110	110	110	110	0.0081	0.9806	0.8209	0.2410
WG (g)	80	80	70	80	80	2	70 b	80[a]	80	80	0.0650	0.0013	0.3107	0.0334
AW (g)	130	120	110	120	130	2	110 b	120[a]	120	120	0.0650	0.3107	0.3745	0.0003
FC (g)	1 380	1 350	1 440	1 350	1 310	24	1 390[a]	1 330[b]	1 350	1 370	0.0650	0.0013	0.0279	0.4073
14 days														
FI (g)	270	270	260	270	270	5	260	270	270	260	0.4276	0.2201	0.1463	0.3848
WG (g)	220	220	200	210	220	6	210	210	220	210	0.4514	0.4120	0.2491	0.0962
AW (g)	260	260	240	250	260	6	250	260	260	250	0.4269	0.4251	0.2632	0.1097
FC (g)	1 250	1 220	1 240	1 250	1 220	19	1 230	1 240	1 230	1 230	0.8423	0.7391	0.8889	0.2116
21 days														
FI (g)	470	450	430	470	470	17	720	700	710	720	0.7171	0.3115	0.5381	0.7891
WG (g)	470	450	430	460	470	11	440	460	460	450	0.2281	0.0611	0.3907	0.2060
AW (g)	510	500	470	500	510	11	480	500	500	490	0.2216	0.0635	0.4017	0.2196
FC (g)	1 440	1 610	1 710	1 490	1 490	48	1 660[a]	1 490[b]	1 550	1 600	0.0179	0.0012	0.2280	0.3024
28 days														
FI (g)	1 380	1 380	1 370	1 350	1 380	13	1 380	1 370	1 370	1 370	0.6134	0.3933	0.6959	0.2098
WG (g)	790	760	730	760	780	23	740	770	760	750	0.1897	0.1738	0.7615	0.3092
AW (g)	830	800	770	810	820	23	780	810	800	790	0.1866	0.1758	0.7679	0.3173
FC (g)	1 720	1 810	1 840	1 740	1 790	39	1 830	1 770	1 780	1 820	0.0678	0.1136	0.3337	0.8431
35 days														
FI (g)	2 310	2 280	2 290	2 290	2 310	23	2 290	2 300	2 290	2 300	0.5984	0.5178	0.4809	0.8050
WG (g)	1 150	1 140	1 080	1 110	1 170	33	1 110	1 140	1 130	1 120	0.5984	0.5178	0.4809	0.8050
AW (g)	1 190	1 180	1 120	1 150	1 210	33	1 150	1 180	1 170	1 160	0.4733	0.4257	0.9043	0.0826
FC (g)	2 020	2 090	2 040	2 040	2 000	43	2 070	2 020	2 070	2 020	0.5916	0.2616	0.2714	0.9706

C × F = contrast between control treatment and addition of fibre sources and levels; LF = fibre levels; SEM = standard deviation of mean; SF = fibre sources; S × L = fibre sources × fibre levels

https://doi.org/10.17221/84/2023-CJAS

Table 3. Decomposing the interaction between weight gain (WG) and feed conversion (FC) at 7 days of age for slow-growing broilers fed diets containing different levels of soluble (SF) and insoluble fibre (IF)

Level of sources of fibre	Weight gain (WG) 7 days		Feed conversion (FC) 7 days	
	soluble	insoluble	soluble	insoluble
2%	0.079[Aa]	0.081[Aa]	1.35[Ab]	1.35[Aa]
4%	0.072[Bb]	0.084[Aa]	1.44[Ba]	1.31[Aa]

[A,B,a,b]Means followed by uppercase letters in the row and lowercase letters in the column differ by Tukey's test at 5% probability

Table 4. Carcass yield and cut yields of slow-growing broilers fed diets containing different levels of soluble (SF) and insoluble fibre (IF) sources at 1 to 35 days of age

Yield (%)	Carcass	Brisket	Thigh	Drumstick	Abdominal fat
Control vs fibre sources and levels					
Control	69.5	18.8	11.4	10.9	1.62
Soluble 2%	70.2	19.1	11.4	10.4	1.47
Soluble 4%	70.1	19.4	11.4	10.4	1.24
Insoluble 2%	69.7	18.4	11.1	10.1	1.19
Insoluble 4%	71.0	18.8	11.3	11.1	0.960
SEM	0.672	0.354	0.202	0.291	0.154
Fibre sources					
Soluble	70.2	19.3	11.4	10.4	1.36
Insoluble	70.4	18.6	11.2	10.6	1.07
Fibre levels					
2%	70.0	18.7	11.3	10.3	1.33
4%	70.6	19.1	11.3	10.8	1.10
P-value					
C × F	0.3141	0.7432	0.8292	0.2548	0.0229
SF	0.7566	0.0594	0.2809	0.4932	0.0745
LF	0.3831	0.3240	0.7531	0.0711	0.1457
S × L	0.2788	0.9289	0.5597	0.0976	0.9637

C × F = contrast between control treatment and addition of fibre sources and levels; LF = fibre levels; SEM = standard deviation of mean; SF = fibre sources; S × L = fibre sources × fibre levels

There was no significant interaction ($P > 0.05$) between fibre sources and levels having effect on any performance parameter, except for weight gain and feed conversion at 7 days of age. The decomposed interaction between fibre sources and levels (Table 3) showed that the addition of 4% SF reduced the WG of broilers by 14.3% and worsened the FC by 9.9% compared to the inclusion of IF.

The carcass yield and cut yields from birds fed different fibre sources and levels were similar to those of animals fed the control diet. However, the dietary inclusion of fibre reduced abdominal fat by 25.2% (Table 4).

Apparent metabolisability of nutrients

The coefficients of apparent metabolisability (CAM) of nutrients in birds fed different fibre sources and levels were similar to those of animals fed the control diet, except for the CAM of DM, which was reduced by 2.62% with the dietary inclu-

https://doi.org/10.17221/84/2023-CJAS

Table 5. Coefficients of apparent metabolisability (%) of dry matter (CAMDM), crude protein (CAMCP) and neutral detergent fibre (CAMNDF) of diets containing different levels of soluble (SF) and insoluble fibre (IF) sources in slow-growing broilers at 1 to 35 days of age

Control vs fibre sources and levels	Coefficients of apparent metabolisability (CAM, %)					
	DM*	CP	NDF	DM	CP	NDF
	10 to 13 days			32 to 35 days		
Control	74.0	54.2	82.3	84.7	74.7	35.9
SF 2%	72.7	45.5	83.3	85.4	72.9	40.5
SF 4%	71.1	50.0	80.5	84.4	70.6	37.1
IF 2%	73.0	58.8	82.1	84.5	78.9	34.1
IF 4%	71.6	56.6	84.3	84.0	73.0	34.9
SEM	0.520	2.80	0.956	0.601	2.35	2.75
Sources						
SF	71.9	47.8[b]	81.9	84.9	71.7	39.8[a]
IF	72.3	57.7[a]	83.2	84.3	75.7	34.0[b]
Fibre levels						
2%	72.9[a]	52.1	82.7	85.0	75.9	37.3
4%	71.4[b]	53.3	82.4	84.2	71.8	36.0
P-value						
C × F	0.0027	0.6355	0.8143	0.6987	0.8040	1.0000
SF	0.5110	0.0013	0.1793	0.2829	0.1017	0.0435
LF	0.0082	0.6857	0.7807	0.2427	0.0709	0.7411
S × L	0.8231	0.2440	0.0134	0.6969	0.4758	0.8111

*Significant contrast at 5% probability between control treatment and addition of fibre sources and levels; [a,b]Means followed by different letters on the same line differ by the Tukey test with a 5% probability

C × F = contrast between control treatment and addition of fibre sources and levels; LF = fibre levels; SEM = standard deviation of mean; SF = fibre sources; S × L = fibre sources vs fibre levels

Table 6. Decomposing the interaction between neutral detergent fibre (NDF) for slow-growing broilers fed diets containing different levels of soluble (SF) and insoluble fibre (IF) sources at 10 to 13 days of age

	CAMNDF (%)	
Level of sources of fibre	soluble	insoluble
2%	83.3[Aa]	82.1[Aa]
4%	80.5[Bb]	84.3[Aa]

[A,B,a,b]Means followed by different letters on the same line differ by Tukey's test at 5% probability

CAMNDF = coefficients of apparent metabolisability of neutral detergente fibre

sion of fibre (Table 5). Birds fed diets containing IF had higher CAM of CP from 10 to 13 days of age and lower CAM of NDF from 32 to 35 days of age. The highest CAM of DM was observed in chicks fed diets containing 2% of additional fibre, regardless of the source (Table 5).

The decomposed interaction between fibre sources and levels showed that the CAM of NDF was similar among birds fed diets containing 2% IF and SF. However, the addition of 4% of IF increased the CAM of NDF by 4.75% in comparison with diets containing SF (Table 6).

Morphometry of digestive tract

The dietary inclusion of fibre sources and levels increased the relative weights of the stomach (proventriculus + gizzard – P + G) in all evaluated weeks, and relative weights of the small intestine (14, 21 and 28 days of age), large intestine (14 days) and liver (28 days). On the other hand, animals fed

Czech Journal of Animal Science, 69, 2024 (4): 139–154

https://doi.org/10.17221/84/2023-CJAS

Table 7. Gastrointestinal tract length (GITL), stomach weight (proventriculus + gizzard – P + G), small intestine weight (SIW), large intestine weight (LIW), pancreas weight (PW) and liver weight (LW) of slow-growing broilers fed diets containing different levels of soluble (SF) and insoluble fibre (IF) sources at 1 to 35 days of age

Control vs treatments	Control	Soluble		Insoluble		SEM	Fibre sources		Fibre levels		*P*-value			
		2%	4%	2%	4%		SF	IF	2%	4%	C × F	SF	LF	S × L
7 days														
GITL (cm)*	93.5	85.5	88.8	83.2	84.2	2.96	87.2	83.7	84.4	86.5	0.0209	0.2560	0.4749	0.7022
P + G (%)*	7.94	8.36	8.37	8.69	10.3	0.36	8.36^{b}	9.50^{a}	8.52^{b}	9.33^{a}	0.2229	0.7624	0.6634	0.1434
SIW (%)	8.10	7.85	7.69	7.59	7.31	0.390	7.77	7.45	7.72	7.50	0.2754	0.4225	0.5678	0.8780
LIW (%)	1.26	1.52	1.49	1.76	1.15	0.180	1.51	1.45	1.64	1.32	0.2827	0.0842	0.1080	0.2827
PW (%)	0.230	0.250	0.270	0.260	0.210	0.010	0.260	0.240	0.260	0.240	0.1899	0.1084	0.2293	0.307
LW (%)	4.33	4.27	3.83	3.86	4.10	0.230	4.05	3.98	4.07	3.96	0.0215	0.0039	0.9794	0.0039
14 days														
GITL (cm)	105	107	110	99.1	98.1	2.37	108a	98.6b	103	104	0.4122	0.0003	0.7020	0.4260
P + G (%)*	5.58	5.86	5.80	6.80	6.78	0.270	5.78^{b}	6.75^{a}	6.26	6.28	0.0104	0.0000	0.0000	0.0000
SIW (%)*	4.86	5.57	6.22	5.17	4.77	0.180	5.89^{a}	4.97^{b}	5.37	5.49	0.0082	0.0000	0.4926	0.0067
LIW (%)*	0.930	1.30	1.22	1.40	1.05	0.070	1.26	1.22	1.35^{a}	1.13^{b}	0.0004	0.6287	0.0051	0.0697
PW (%)	0.240	0.230	0.230	0.230	0.230	0.010	0.230	0.230	0.230	0.230	0.8912	0.9484	0.6418	0.7802
LW (%)*	3.01	3.48	3.28	3.10	1.02	0.100	3.38^{a}	2.06^{b}	3.29^{a}	2.15^{b}	0.0082	0.0004	0.9264	0.9887
21 days														
GITL (cm)	115	113	120	118	118	2.99	116	118	115	119	0.0082	0.0004	0.9264	0.9887
P + G (%)*	4.47	4.55	5.10	5.87	5.86	0.200	4.82^{b}	5.87^{a}	5.21	5.48	0.4805	0.1777	0.8383	0.5990
SIW (%)*	3.62	4.01	4.52	3.83	3.70	0.150	4.26^{a}	3.77	3.92	4.11	0.0255	0.0025	0.2286	0.0455
LIW (%)	0.900	0.770	0.850	0.810	0.830	0.040	0.810	0.820	0.790	0.840	0.1026	0.8556	0.2497	0.5213
PW (%)	0.330	0.330	0.330	0.350	0.290	0.030	0.330	0.320	0.340	0.310	0.8727	0.7624	0.4489	0.3075
LW (%)	2.73	2.76	2.68	2.56	2.59	0.100	2.72	2.58	2.66	2.64	0.0004	0.0000	0.1742	0.1652
28 days														
GITL (cm)	136	136	140	137	129	3.24	138	133	137	135	0.9932	0.1188	0.5799	0.0883
P + G (%)*	4.07	4.21	4.61	5.24	5.18	0.190	4.41^{b}	5.21^{a}	4.72	4.89	0.0474	0.2706	0.0473	0.1597
SIW (%)*	3.39	3.45	4.92	3.87	3.09	0.120	4.18^{a}	3.48^{b}	3.66^{b}	4.01^{a}	0.0025	0.0000	0.0069	0.0000
LIW (%)	0.810	0.900	1.070	0.940	0.790	0.060	0.990^{a}	0.870^{b}	0.920	0.930	0.0025	0.0000	0.0000	0.0004

https://doi.org/10.17221/84/2023-CJAS

Table 7 to be continued

Control vs treatments	Control	Soluble		Insoluble		SEM	Fibre sources		Fibre levels		*P*-value			
		2%	4%	2%	4%		SF	IF	2%	4%	C × F	SF	LF	S × L
PW (%)	0.280	0.250	0.300	0.300	0.220	0.020	0.280	0.260	0.270	0.260	0.0682	0.0371	0.8469	0.0062
LW (%)*	2.22	2.45	2.41	2.48	2.22	0.070	2.43	2.35	2.47^{a}	2.32^{b}	0.7439	0.3383	0.5709	0.0016
35 days														
GITL (cm)	138	134	140	141	141	3.99	137	141	137	140	0.9279	0.3454	0.4661	0.4475
P + G (%)*	3.56	3.70	3.62	4.37	4.52	0.170	3.66^{b}	4.45^{a}	4.04	4.07	0.7575	0.6658	0.8609	0.2820
SIW (%)	2.51	2.64	2.91	2.48	312	0.100	2.78^{a}	2.47^{b}	2.56	2.69	0.3325	0.0043	0.2219	0.1398
LIW (%)	0.750	0.740	0.690	0.610	0.660	0.030	0.710^{a}	0.640^{b}	0.670	0.680	0.0504	0.0295	0.9724	0.1630
PW (%)	0.230	0.190	0.210	0.180	0.190	0.020	0.200	0.190	0.190	0.200	0.0681	0.4288	0.3204	0.7501
LW (%)	1.85	1.85	1.96	1.90	1.82	0.090	1.90	1.86	1.87	1.89	0.0115	0.0000	0.8379	0.4952

*Significant contrast at 5% probability between control treatment and addition of fibre sources and levels; [a,b]Means followed by different letters on the same line differ by the Tukey test with a 5% probability

C × F = contrast between control treatment and addition of fibre sources and levels; LF = fibre levels; SEM = standard deviation of mean; SF = fibre sources; S × L = fibre sources vs fibre levels

Table 8. Decomposing the interaction between proventriculus + gizzard weight (7 days), pancreas weight (7 and 14 days), small intestine weight (14, 21 and 28 days), liver weight (14 days) and large intestine weight (28 days) of slow-growing broilers fed diets containing different levels of soluble (SF) and insoluble fibre (IF) sources

Level of sources	Proventriculus + gizzard		Pancreas		Small intestine		Liver	
	7 days				14 days			
	soluble	insoluble	soluble	insoluble	soluble	insoluble	soluble	insoluble
2%	8.36^{Aa}	8.69^{Ab}	0.250^{Aa}	0.260^{Aa}	5.57^{Ab}	5.17^{Aa}	3.48^{Aa}	3.10^{Aa}
4%	8.37^{Ba}	10.3^{Aa}	0.270^{Aa}	0.210^{Bb}	6.22^{Aa}	4.77^{Bb}	3.28^{Aa}	1.02^{Bb}
Level of sources	**Small intestine**		**Small intestine**		**Large intestine**		**Pancreas**	
	21 days		28 days					
2%	4.01^{Ab}	3.83^{Aa}	3.45^{Ab}	3.87^{Aa}	0.90^{Ab}	0.94^{Aa}	0.25^{Aa}	0.29^{Aa}
4%	4.52^{Aa}	3.70^{Ba}	4.92^{Aa}	3.09^{Bb}	1.07^{Aa}	0.79^{Ba}	0.31^{Aa}	0.23^{Bb}

[A,B,a,b]Means followed by uppercase letters in the row and lowercase letters in the column differ by Tukey's test at 5% probability

Original Paper

Czech Journal of Animal Science, 69, 2024 (4): 139–154

https://doi.org/10.17221/84/2023-CJAS

Table 9. Villus height (V, μm), crypt depth (C, μm) and villus to crypt ratio (V/C) of the duodenum of slow-growing broilers fed diets containing different levels of soluble (SF) and insoluble fibre (IF) sources at 1 to 35 days of age

	V (μm)	C (μm)	V/C*	V (μm)	C (μm)*	V/C	V (μm)	C (μm)	V/C	V (μm)	C (μm)	V/C	V (μm)	C (μm)	V/C
Control vs fibre sources and levels															
	7 days			14 days			21 days			28 days			35 days		
Control	715	147	5.12	888	139	6.28	976	183	5.32	981	195	4.88	845	170	4.85
Soluble 2%	741	147	5.13	962	170	5.60	1 016	212	4.85	900	197	4.44	947	194	5.10
Soluble 4%	656	149	4.54	982	164	5.85	985	193	5.19	1 113	210	5.11	1 154	191	5.40
Insoluble 2%	706	171	3.89	958	154	5.83	964	190	5.13	993	201	4.79	881	186	4.84
Insoluble 4%	692	169	3.86	987	153	6.49	963	196	4.98	1 096	214	5.16	869	179	4.80
SEM	34.2	8.40	0.210	43.5	7.86	0.440	48.7	10.4	0.280	60.9	13.3	0.290	42.1	9.22	0.210
Fibre sources															
Soluble	699	148[b]	4.8[a]	972	167	5.73	1 001	203	5.02	1 007	203	4.78	977[a]	192	5.25[a]
Insoluble	699	170[a]	3.8[b]	972	153	6.16	963	193	5.06	1 045	208	4.98	881[b]	183	4.82[b]
Fibre levels															
2%	723	159	4.51	960	162	5.71	990	201	4.99	947[b]	199	4.62	914	190	4.97
4%	674	159	4.20	985	158	6.17	974	194	5.08	1 105[a]	212	5.14	945	185	5.10
P-value															
C × F	0.6816	0.2189	0.0025	0.0912	0.0200	0.4495	0.9091	0.2154	0.3715	0.5158	0.4715	0.9916	0.0812	0.0933	0.4512
SF	0.9969	0.0135	0.0001	0.9998	0.0967	0.3328	0.4507	0.3626	0.8980	0.5374	0.7596	0.4960	0.0283	0.2991	0.0485
LF	0.1616	0.9919	0.1482	0.5774	0.6012	0.3051	0.7503	0.5328	0.7521	0.0136	0.3163	0.0854	0.4736	0.5755	0.5286
S × L	0.3102	0.8261	0.1850	0.9155	0.7498	0.6450	0.7568	0.2306	0.3866	0.3745	0.9981	0.6228	0.4738	0.8216	0.4253

*Significant contrast at 5% probability between control treatment and addition of fibre sources and levels; [a,b]Means followed by different letters on the same line differ by Tukey's test at 5% probability

C × F = contrast between control treatment and addition of fibre sources and levels; LF = fibre levels; SEM = standard deviation of mean; SF = fibre sources; S × L = fibre sources vs fibre levels

https://doi.org/10.17221/84/2023-CJAS

Table 10. Villus height (V, μm), crypt depth (C, μm) and villus to crypt ratio (V/C) of the caecum of slow-growing broilers fed diets containing different levels of soluble (SF) and insoluble fibre (IF) sources at 1 to 35 days of age

	V (μm)	C (μm)	V/C	V (μm)	C (μm)	V/C	V (μm)	C (μm)	V/C	V (μm)	C (μm)	V/C*	V (μm)	C (μm)	V/C
Control vs fibre sources and levels															
	7 days			14 days			21 days			28 days			35 days		
Control	186	51.2	3.66	158	64.1	2.55	219	71.3	3.10	226	59.5	4.01	232	56.7	4.20
Soluble 2%	190	60.7	3.43	144	64.4	2.26	238	71.9	3.14	240	64.7	3.63	220	54.0	4.10
Soluble 4%	196	65.1	3.06	156	60.9	3.03	212	66.2	3.26	221	62.1	3.71	212	57.4	3.75
Insoluble 2%	166	58.5	2.89	173	62.7	3.11	243	64.1	3.81	193	60.7	3.35	231	57.4	4.08
Insoluble 4%	169	48.0	3.53	187	66.0	2.86	260	73.3	3.60	257	59.4	3.96	218	59.5	3.70
SEM	12.7	4.61	0.250	9.58	3.80	0.290	9.60	3.65	0.230	10.3	2.38	0.130	10.9	2.42	0.310
Fibre sources															
Soluble	193	62.9[a]	3.24	150[b]	62.6	2.64	225[b]	69.1	3.71[a]	231	63.4	3.67	216	55.7	3.73
Insoluble	168	53.2[b]	3.21	180[a]	64.4	2.98	252[a]	68.7	3.20[b]	225	60.1	3.66	225	58.5	3.89
Fibre levels															
2%	178	59.6	3.16	158	63.6	2.68	241	68.0	3.48	217[b]	62.7	3.49[b]	225	55.7	3.90
4%	182	56.5	3.29	172	63.4	2.94	236	69.8	3.43	239[a]	60.7	3.84[a]	215	58.5	3.73
P-value															
C × F	0.6800	0.1903	0.1331	0.5213	0.8908	0.4128	0.0831	0.5567	0.1807	0.8316	0.3993	0.0310	0.3571	0.8775	0.2723
SF	0.0559	0.0432	0.8850	0.0038	0.6560	0.2450	0.0089	0.9235	0.362	0.5869	0.1740	0.8916	0.4187	0.2622	0.6145
LF	0.7352	0.5101	0.6005	0.1680	0.9762	0.3716	0.6475	0.6396	0.8481	0.0353	0.4156	0.0166	0.3613	0.2594	0.5851
S × L	0.9076	0.1169	0.0511	0.9157	0.3722	0.0872	0.0334	0.0493	0.4866	0.0003	0.7951	0.0617	0.8273	0.7914	0.4981

*Significant contrast at 5% probability between control treatment and addition of fibre sources and levels; [a,b]Means followed by different letters on the same line differ by Tukey's test at 5% probability; [1]Standard deviation from average

C × F = contrast between control treatment and addition of fibre sources and levels; LF = fibre levels; SEM = standard deviation of mean; SF = fibre sources; S × L = fibre sources vs fibre levels

https://doi.org/10.17221/84/2023-CJAS

Table 11. Decomposing the interaction between caecal villi at 21 days and 28 days of age in slow-growing broilers fed diets containing different levels of soluble (SF) and insoluble fibre (IF) sources

Level	Villus 21 days		Crypt 21 days		Villus 28 days	
	soluble	insoluble	soluble	insoluble	soluble	insoluble
2%	238[Aa]	243[Aa]	71.9[Aa]	64.1[Aa]	240[Aa]	193[Bb]
4%	212[Ba]	260[Aa]	66.2[Aa]	73.3[Aa]	221[Ba]	257[Aa]

[A,B,a,b]Means followed by uppercase letters in the row and lowercase letters in the column differ by Tukey's test at 5% probability

the control diet had a longer gastrointestinal tract (7 days of age) and higher liver weight (14 days of age) (Table 7).

The use of IF as a source resulted in a higher % of P + G at any age, however it decreased the liver (14 days old chickens), small intestine (21, 28 and 35 days of age) and large intestine (28 and 35 days of age). The dietary inclusion of 4% additional fibre resulted in higher P + G at 7 days of age and small intestine at 28 days.

There was a significant interaction ($P < 0.05$) between fibre sources and levels for the relative weights of proventriculus + gizzard and pancreas (7 days), small intestine and liver (14 days), small intestine (21 days) and small intestine, large intestine and pancreas (28 days) (Table 7). The decomposed interaction between fibre sources and levels showed no difference in the development of the digestive organs among birds fed diets containing 2% additional fibre, regardless of the source. However, the inclusion of 4% SF resulted in higher % of small intestine at 14, 21 and 28 days of age and liver (28 days), whereas higher values of IF in diets resulted in higher % of P + G (7 days) and lower % of the pancreas (7 and 28 days), small intestine and liver (14 days) (Table 8).

Intestinal histomorphometry

The histomorphometry of the duodenum of birds fed different treatments was similar to that of chickens fed the control diet. Birds fed diets containing SF had a higher villus height at 35 days of age. Even, diets with SF increased the villus to crypt ratio at 7 and 35 days of age. However, there was a reduction in the villus to crypt ratio at 7 days of age and an increase of 15.54% in the crypt depth at 14 days with the fibre inclusion in the diet. The dietary inclusion of 4% additional fibre increased the villus height at 28 days, regardless of the source (Table 9).

The histomorphometry of the caecum of birds fed different fibre sources and levels was similar to that of chickens fed the control diet (Table 10). Higher crypt depth and lower villus height were observed for birds fed the diet with SF at 7 and 14 days of age, respectively.

There was a significant interaction ($P < 0.05$) between fibre sources and levels for villus height at 21 and 28 days of age and crypt depth at 21 days (Table 11). The addition of 4% SF decreased the villus height by 10.9% and 7.9 % at 21 and 28 days of age, respectively, in comparison with birds fed diets containing IF (Table 11). However, at 28 days of age the inclusion of 2% IF in the diet increased the villus height of the caecum by 24.9% in comparison with birds fed diets containing SF.

DISCUSSION

The dietary inclusion of fibre little affected the performance of slow-growing broilers, and the effects varied with fibre source, fibre level and phase of production.

This is by other researchers who have reported that small additions of dietary fibre do not affect negatively the growth performance of broilers (Tejeda and Kim 2021).

Dietary fibre has been considered as a diluent of the diet and an anti-nutritional factor in poultry diets (Gonzalez-Alvarado et al. 2010), although the inclusion of moderate levels of fibre can have a positive effect on weight gain, digesta viscosity, starch digestibility and feed conversion in poultry (Hetland et al. 2003; Shakouri et al. 2006; Mateos et al. 2012; Kheravii et al. 2017).

The dietary inclusion of 4% of SF worsened the WG and FC of birds at 7 days of age, while worsening in AC in relation to the control diet was observed only at 21 days of age. This can be attributed to the differences in fibre sources. The viscous sol-

https://doi.org/10.17221/84/2023-CJAS

uble fibre is associated with growth performance impairment due to the disruption of normal enzymatic activity and nutrient digestibility (Hetland et al. 2004; Saki et al. 2011).

It is emphasized that the dietary inclusion of 2% of SB sources and up to 4% of IF did not affect the chick performance. Dietary sources of insoluble fibre increase the WG and FC of broilers during the starter period because the dilution effect of fibre tends to increase the feed intake and, consequently, the live weight of animals (Guzman et al. 2013; Jimenez-Moreno et al. 2013). Another hypothesis suggests that birds can maintain their normal weight gain when fed diets diluted with insoluble fibre due to increased digestion capacity and/or gastrointestinal transit time (Hetland et al. 2003). Consequently, increased feed intake may be associated with rapid gastric emptying (Shakouri et al. 2006). However, our data showed that the inclusion of IF did not affect feed intake in any of the evaluated periods. Thus, the higher feed conversion of broilers fed diets containing this fibre source may have been caused by an improvement in nutrient utilization, as observed for the CAM of CP and NDF.

The effects of dietary fibre on the utilization of nutrients by poultry are still a controversial topic. Tejeda and Kim (2021) stated that the dietary inclusion of soluble and insoluble fibre makes digestion challenging for birds that will then consume more feed but with reduced nutrient utilization. This occurs due to the hydration of non-starch polysaccharides, which increases digesta viscosity and inhibits nutrient digestion by enzymes. As a result, the absorption of nutrients throughout the digestive tract is reduced.

However, broiler chicks fed diets containing insoluble fibre (oat hulls) at 25 g/kg also had higher crude protein digestibility (Jimenez-Moreno et al. 2013). According to Jimenez-Moreno et al. (2011), the increase in the CAM of nutrients with the inclusion of moderate levels of insoluble fibre is associated with improvements in the gizzard function and mucosal structure of the small intestine.

Our results reinforce the hypothesis that insoluble fibre (IF) contributes to nutrient digestibility more positively than soluble fibre (SF) sources in slow-growing chicks. Jimenez-Moreno et al. (2013) demonstrated that the dietary inclusion of soluble fibre from beet pulp reduced the CAM of DM in comparison with the control diet, thus corroborating the results observed in this study.

Although the fibre levels and sources affected the relative weight of digestive organs, only the levels of abdominal fat were positively affected by fibre inclusion amongst the evaluated carcass characteristics. According to Freitas et al. (2014), fat deposition is directly proportional to the amount of energy for fat synthesis. Therefore, excessive energy intake must be avoided to maximize daily protein deposition and minimize fat deposition.

On the other hand, higher levels of dietary fibre can reduce nutrient utilization and, consequently, metabolizable energy of the feed, which decreases the growth rate of birds (Bedfor 1995). There was no reduction in body weight at 35 days of age that could explain the lower deposition of abdominal fat in broilers fed diets with different fibre sources and levels. However, it is essential to highlight that slow-growing broilers have lower energy requirements than conventional broilers (Mendonca et al. 2008). Although diets containing additional fibre may have reduced levels of available energy, the amount of supplied energy was sufficient to maintain the animal performance without demanding energy from abdominal fat. It is worth mentioning that the consumer market aimed at slow-growing poultry demands carcasses with reduced fat content. Therefore, the inclusion of fibre in the feed can be a nutritional alternative to decrease the fat content in the carcass without affecting the broiler performance.

The effects of fibre on the development of the gastrointestinal tract varied with the type and amount of fibre. Although the inclusion of fibre reduced the total length of the GIT in comparison with animals fed the control diet, the dietary inclusion of fibre resulted in greater relative weights of P + G, SI, LI and liver, regardless of the source. Gonzales-Alvarado et al. (2007) reported the increased intestinal size in broilers fed diets containing additional fibre from sunflower hulls. According to the authors, the presence of fibre induces the increased intestinal activity in an attempt to improve the digestion and absorption of the diet with high viscosity. Consequently, it also contributes to the development of the GIT.

Freitas et al. (2014) also studied variations in the size of the GIT and liver in broilers fed diets containing increasing levels of NDF. The weights of the liver and intestines were higher in animals fed diets containing 18.5% NDF than in those receiving diets with 14.5% NDF. The liver is the main metabolic

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organ in the body, therefore nutritional factors can interfere with its function. Moreover, the modulation of metabolic activity can also cause changes in the liver size.

However, the positive effects of additional fibre on intestinal development were more noticeable in broilers fed diets containing a source of soluble fibre (SF). According to Gonzalez-Alvarado et al. (2007), feeding insoluble fibre sources results in the shorter small intestine, and this effect can be explained by the lower density of nutrients, which reduces the surface area required for absorption.

The dietary inclusion of IF at 4% was more effective in increasing the weight of the proventriculus + gizzard than in the development of the GIT organs, such as SI and pancreas. Jimenez-Moreno et al. (2010) demonstrated that broilers fed diets containing 3% of microcrystalline cellulose, oat hulls and beet pulp showed the improved gizzard development from 1 to 21 days of age, especially when oat hulls were used as a fibre source.

Gonzalez-Alvarado et al. (2010) and Jimenez-Moreno et al. (2019) also reported that broilers fed diets containing insoluble fibre (oat hulls and wood shavings) had higher proventriculus and gizzard weights. Thicker particles tend to accumulate and stay in the gizzard for more extended periods. As a result, these particles mechanically stimulate the muscular development of the P + G (Mateos et al. 2012).

According to Jimenez-Moreno et al. (2019), a well-developed gizzard is associated with strong contractions of the muscular layers, which ensures the complete grinding of the feed and helps to regulate the flow of the digesta to the small intestine, facilitating the mixing of the chyme and the gastric juices. Coarse particles are retained until they reach the ideal size (Hetland et al. 2005), while liquids and soluble material pass directly to the duodenum. The accumulation of insoluble fibre in the gizzard slows the passage rate of the fibre fraction. However, this phenomenon will only occur for the coarser and insoluble fibre fraction (Hetland et al. 2004).

A well-developed gizzard is a desirable morphological characteristic in slow-growing broilers. This category is recommended for the alternative poultry market since broilers are raised in semi-intensive systems after the starter period. Thus, nutritional strategies that maximize the development of the digestive system of these animals are essential to adapt them to the consumption of fibrous foods, such as forage available in the grazing area. Forage intake plays a crucial role in product differentiation, especially affecting meat colour and tenderness, which, among other factors, are stimulated by grazing activity.

The development of the duodenal mucosa was greater in broilers fed diets containing SF than in those receiving IF. In contrast, Jimenez-Moreno et al. (2013) reported that the dietary inclusion of insoluble fibre resulted in longer villi and a higher villus-to-crypt ratio in the duodenum of broilers. The authors also reported a reduction in villus height and villus-to-crypt ratio in broilers fed soluble fibre sources (beet pulp, citrus pectin, and xanthan gum) due to reduced nutrient utilization.

On the other hand, Nabuus (1995) stated that the increase in villus height and villus-to-crypt ratio in birds fed diets containing SF can be attributed to better nutrient absorption and lower energy loss with cell renewal. In our study, the dietary inclusion of SF reduced the CAM of nutrients at all ages. Therefore, the higher availability of nutrients from this fibre type was not a trophic factor for the development of the duodenal villi of slow-growing broilers during the starter period. However, the dietary inclusion of IF at 7 days of age led to the greater crypt depth of the duodenum, which indicates that this fibre source was responsible for a higher rate of cell renewal and, consequently, less developed villi.

The dietary inclusion of 2% IF increased the villus height in the caecum of slow-growing broilers. In addition, positive effects on the caecal villus height were observed in broilers fed diets containing 4% IF.

SF positively influenced the development of the intestinal mucosa because it is more readily fermented by intestinal bacteria in the large intestine. As a result, it contributes to the production of short-chain fatty acids (SCFA), primarily acetate, propionate and butyrate, in addition to H_2O and other gases such as carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4) (Montagne et al. 2003). These SCFA act as an energy source for the intestinal mucosa, in addition to protecting the body against several pathogens, diarrhoea and intestinal inflammation (Goulart et al. 2016; Qiu et al. 2022).

Moreover, fibre fermentation in the intestine improves organ morphology by increasing the absorption area and renewing the epithelial cells, which act as immunostimulants. Thus, the manipulation

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of diets aimed at providing balanced levels of dietary fibre can lead to such effects without the need of additive supplementation (Goulart et al. 2016).

CONCLUSION

The dietary inclusion of IF at the level of 4% maintains the performance, improves metabolism of nutrients and development of the proventriculus + gizzard of slow-growing broilers. In addition, the dietary inclusion of SF improves morphological and histomorphological parameters of young slow-growing broilers.

Acknowledgment

The authors would like to thank the Instituto Federal Goiano for the financial and economic support in conducting this research.

Conflict of interest

The authors declare no conflict of interest.

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Received: June 14, 2023
Accepted: April 2, 2024
Published online: April 30, 2024