Optimising barley inclusion in broiler chickens' diets

by Mehdi Toghyani and Sonia Liu
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A milestone report as part of the project 'The impact of climate on sorghum utilisation in poultry diets'

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Introduction

Feed represents the highest variable cost of meat chicken production, accounting for 60-80% of the total cost depending on the farming system, i.e., intensive, free-range or organic rearing systems. As a nutrient, dietary energy is the largest and most expensive component of broiler chickens' diets, often supplied by high inclusion (60-70%) of cereal grains. In Australia, a wheat-based diet is commonly used in poultry production, and this diet is often supplemented with exogenous xylanase to mitigate the negative impact of non-starch polysaccharides (NSPs) on birds' growth performances.

Barley (*Hordeurn vulgare L.*), the fourth-most produced grain globally, can also be included in broiler diets as an energy-contributing ingredient. However, inclusion of barley in broiler diets is limited, mainly due to its high fibre content, low energy (ME) and high levels of soluble NSPs (Jacob and Pescatore, 2012). On a dry matter basis, barley has 33.3% and 55.2% higher crude fibre and 46.5% and 95.0% higher soluble NSPs than wheat and corn, respectively (Choct, 2006; Bach Knudsen, 2014). The concentration of soluble β-glucan is almost 10 folds higher than that of wheat (Jacob and Pescatore, 2014). Barley has a lower and more variable (40-55%) starch concentration than corn (62-67%) and wheat (55-60%). The protein content of barley is often more than 2% higher than corn, but less than wheat – although when expressed as percentage of total crude protein, barley amino acid profile is comparable to corn and wheat, and its protein and amino acid digestibility coefficients are much lower (McNab and Shannon, 1974). Also, due to its high fibre and low starch content, high inclusion of barley has been reported to compromise pellet quality and durability.

The high concentration of soluble NSPs, particularly β-glucan, have long been identified as the main antinutritive factors in barley, responsible for increasing gut viscosity (White et al., 1983) and sticky droppings in chickens (Gohl et al., 1978), as well as impairing nutrient digestibility (Salih et al., 1991). This eventually led to the development and use of commercial β-glucanases (McNab and Smithard, 1992). Ever since, supplementation of barley-based broiler diets with multi-carbohydrase enzymes targeting mainly the soluble NSPs have been comprehensively studied and reported to increase feed intake, weight gain and flock uniformity, improve feed efficiency, and enhance nutrient use (Hesselman and Åman, 1986; Marquardt et al., 1994; Almirall et al., 1995; Bergh et al., 1999) by reducing digesta viscosity (Almirall et al., 1995; Józefiak et al., 2006), releasing encapsulated nutrients (Hesselman and Åman, 1986; Bedford, 1996), and modifying gut microbiota through the supply of prebiotic oligosaccharides (González-Ortiz et al., 2017; Bedford, 2018). Nonetheless, the NSPase application in barley-based diets has not always generated consistent results and wide variability in responses to enzyme supplementation has been reported (Bao et al., 2013). The published literature on the recommendation for barley inclusion, either with or without β-glucanases or other NSPase enzymes, has also been contradictory. This has resulted in a range of inclusion levels being recommended in broiler diets, from as little as 100 g/kg to more than 500 g/kg. The variations in the chemical and physical characteristics of barley (Izydorczyk et al., 2000), the stage of ripeness, the age of the birds when barley has been introduced into the diet, the source of the nutrient composition data used for barley, the grain profile in the background diet, and the differences in enzyme cocktails tested might to some extent explain this discrepancy in published data.

Considering current market trends for Australian barley and the lack of updated literature, it is necessary to re-establish the optimum inclusion rate of barley in meat chicken diets. This would enable nutritionists to confidently formulate more-cost-effective diets and focus on maximum profitability. The present study was designed to quantify the optimum inclusion rate of barley for different growing phases and to test whether alongside a commercial xylanase a higher dose of β-glucanase is needed to fully counteract the negative effects of high barley inclusion on the performance meat chickens.

Methodology

The experimental protocols and procedures for the present study were reviewed and approved by the University of Sydney Animal Ethic Committee. The feeding study consisted of eight dietary treatments arranged as a 4 x 2 factorial layout. The experimental factors were four incremental levels of barley inclusion with or without β-glucanase at 304 U/kg (Table 1). All the diets were formulated to have a xylanase activity of 2440 U/kg and 1300 FTU/kg of phytase (only the matrix for Ca, AvP and Na was applied). Each treatment was replicated six times, with 18 birds per replicate. The diets were wheat-soybean meal-based (containing both canola meal and seeds to be consistent with commercial practice) and formulated to meet birds' nutrient requirements based on breeder recommendations for starter (1-9 d), grower (9-23 d), finisher (23-35 d) and withdrawal (35-42 d) periods (Aviagen, 2019; Tables 2 to 5). Diets were steam-pelleted at a conditioning temperature of 80 °C and were offered *ad lib*. The starter diets were further crumbled to maximize feed intake. Pellet durability index (PDI) of all diets (excluding starter diets) were tested, in triplicate, using the NHP 200 New Holman Automatic Pellet Tester (TekPro Ltd, Norfolk, UK).

Table 1. Dietary treatment layout

Treatments	Barley inclusion %			
	Starter	Grower	Finisher	Withdrawal
T1 + Xylanase 65g/T	0	0	0	0
T2 + Xylanase 65g/T	0	7.5	15	22.5
T3 + Xylanase 65g/T	7.5	15	22.5	30
T4 + Xylanase 65g/T	15	22.5	30	37.5
T5 + Axtra XB 200g/T	0	0	0	0
T6 + Axtra XB 200g/T	0	7.5	15	22.5
T7 + Axtra XB 200g/T	7.5	15	22.5	30
T8 + Axtra XB 200g/T	15	22.5	30	37.5

Phytase at 1300 FTU/kg Ca, AvP and Na only, Xylanase at 2440 U/kg across all diets, B-Glucanase at 304 U/kg in T5 to T8.

Prior to diet formulation, representative subsamples of wheat, barley, soybean meal, meat and bone meal, canola meal and canola seed were analysed by near-infrared spectroscopy to predict proximate analysis, digestible amino acid concentrations, and AME using AMINONIR®PROX, AMINONIR®NIR, and AMINONIR® NRG (Evonik Nutrition & Care, Hanua, DE), respectively. Accordingly, the predicted AME values of 3220 and 2800 kcal/kg for wheat and barley, respectively, were used to formulate diets.

The initial and final bodyweights (pen basis) were determined for each feeding phase and feed intakes were recorded, from which feed conversion ratios (FCR) were calculated. The incidence of dead or culled birds was recorded daily and their bodyweights used to adjust FCR calculations. On day 42, bodyweight corrected FCR (BWc FCR) was also calculated and presented as there were treatment-associated differences in bodyweight. This correction was achieved by considering a 50 g difference in bodyweight equivalent to 1 point in FCR. The primary reason for this additional calculation was to accommodate the fact that under commercial growing conditions, birds are reared to a target weight and not a fixed age.

On day 42, four birds from each pen were randomly selected and euthanised to collect distal ileal digesta samples to measure water content. Skinless breast meat (separating major and minor muscles), thigh and drumstick (leg quarter), and abdominal fat pad were removed, weighed and calculated as a percentage of live body weight. Breast major muscle was also visually examined and scored for the occurrence of woody breast (figure 1) and white striping (figure 2; Kuttappan et al. 2012).

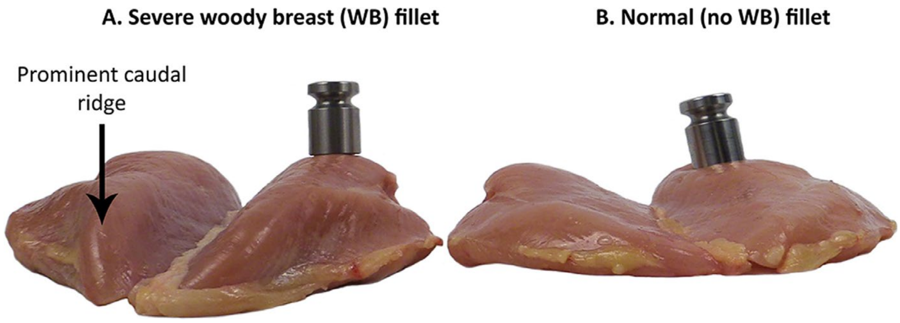

Figure 1. Comparison of severe woody breast (WB) and normal fillets (A and B, respectively). Each fillet has a 200 g weight resting on the cranial portion of the fillet. The severe WB fillet shows no visual signs of compression while the weight on the normal fillet compresses the surface of the fillet. The breast fillets were given a score of 0 = no woody breast, 1 = moderate, 2 = severe and 3 = extreme woody breast conditions.

Figure 2. Modified visual scoring scale for white striping in broiler breast fillets where 0 = normal, 1 = moderate, 2 = severe, and 3 = extreme. Normal – No distinct white lines. Moderate – Small white lines (generally < 1 mm thick) apparently visible on the fillet surface. Severe – Large white lines (1-2 mm thick) very visible on the fillet surface. Extreme – Thick white bands (> 2 mm thickness) covering almost all the surface of the fillet.

Statistical analysis

Data was checked for normality and then subjected to statistical analysis using two-way ANOVA of GLM procedure of JMP®13.0.0 (SAS Institute Inc., JMP Software, Cary, NC, US) to assess the main effects of barley inclusion levels, β-glucanase supplementation, and their interaction. Each pen was considered an experimental unit and the values presented in the tables are means with pooled standard error of mean (SEM). If a significant effect was detected, differences between treatments or main effects were separated by least square differences test. Significance was considered at $P < 0.05$ and $P < 0.1$ was indicated as a trend.

Table 2. Compositions and calculated nutrient specifications in starter diets

Ingredients %	No barley	Barley 7.5%	Barley 15%
Wheat 14% CP – 3200 ME	65.445	56.163	46.880
Soybean meal	24.278	25.435	26.592
Canola exp 36/9	3.000	3.000	3.000
Meat meal 55%	2.391	2.329	2.266
Lime fine 38%	1.057	1.064	1.071
Canola seeds	1.000	1.000	1.000
Canola oil	0.943	1.679	2.414
MCP	0.391	0.374	0.358
Lysine HCL	0.364	0.339	0.313
DL-Methionine	0.247	0.256	0.265
Sodium bicarbonate	0.219	0.193	0.167
Vit/min Premix[1]	0.200	0.200	0.200
Salt	0.200	0.211	0.221
L-Threonine	0.152	0.147	0.141
Choline chloride	0.050	0.050	0.050
L-Valine	0.029	0.029	0.028
Axtra phy 10000	0.013	0.013	0.013
Xylanase	0.065	0.065	0.065
Barley 11% CP – 2850 ME	-	7.500	15.000
Cost ($/tonne)	544.0	540.28	536.56
Calculated composition			
ME (kcal/kg)	2960	2960	2960
NE (kcal/kg)	2323	2328	2333
Dry matter %	90.6	90.7	90.7
Crude protein %	23.5	23.5	23.5
Starch-protein ratio	1.689	1.617	1.540
T.Dig.Lys.Poult %	1.243	1.243	1.243
T.Dig.Met.Poult %	0.561	0.566	0.572
T.Dig.M+C.Poult %	0.922	0.922	0.922
T.Dig.Thr.Poult %	0.835	0.835	0.835
T.Dig.Iso.Poult %	0.845	0.845	0.845
T.Dig.Leu.Poult %	1.507	1.500	1.494
T.Dig.Trp.Poult %	0.257	0.257	0.256
T.Dig.Arg.Poult %	1.333	1.340	1.347
T.Dig.His.Poult %	0.515	0.512	0.509
T.Dig.Val.Poult %	0.970	0.970	0.970
Crude fat %	3.359	4.066	4.773
Crude fibre %	3.097	3.384	3.672
Starch %	39.7	38.0	36.2
Calcium %	0.950	0.950	0.950
Av. Phos %	0.475	0.475	0.475
Total Phos %	0.509	0.520	0.530
Sodium %	0.190	0.190	0.190
Chloride %	0.270	0.270	0.270
Potassium %	0.833	0.853	0.874
Na+K-Cl mEq/kg	219	224	229

[1]Vitamin concentrate supplied per kilogram of diet: retinol, 12000 IU; cholecalciferol, 5000 IU; tocopheryl acetate, 75 mg, menadione, 3 mg; thiamine, 3 mg; riboflavin, 8 mg; niacin, 55 mg; pantothenate, 13 mg; pyridoxine, 5 mg; folate, 2 mg; cyanocobalamin, 16 μg; biotin, 200 μg; cereal-based carrier, 149 mg; mineral oil, 2.5 mg. Trace mineral concentrate supplied per kilogram of diet: Cu (sulphate), 16 mg; Fe (sulphate), 40 mg; I (iodide), 1.25 mg; Se (selenate), 0.3 mg; Mn (sulphate and oxide), 120 mg; Zn (sulphate and oxide), 100 mg; cereal-based carrier, 128 mg; mineral oil, 3.75 mg.

Table 3. Compositions and calculated nutrient specifications in grower diets

Ingredients %	No barley	Barley 7.5%	Barley 15%	Barley 22.5%
Wheat 14% CP – 3200 ME	67.571	58.281	48.991	39.701
Soybean meal	17.365	18.593	19.820	21.047
Meat meal 55%	4.377	4.200	4.024	3.848
Canola exp 36/9	4.000	4.000	4.000	4.000
Canola seeds	3.000	3.000	3.000	3.000
Canola oil	1.603	2.354	3.105	3.857
Lime fine 38%	0.721	0.743	0.765	0.786
Lysine HCL	0.351	0.326	0.301	0.276
Sodium bicarbonate	0.239	0.215	0.190	0.165
Dl-Methionine	0.210	0.219	0.228	0.237
Vit/Min Premix	0.200	0.200	0.200	0.200
Salt	0.150	0.161	0.173	0.185
L-threonine	0.129	0.123	0.118	0.113
Choline chloride	0.050	0.050	0.050	0.050
Axtra phy 10000	0.013	0.013	0.013	0.013
Xylanase	0.065	0.065	0.065	0.065
Barley 11% CP – 2850 ME	-	7.500	15.000	22.500
Cost ($/Tonne)	537.76	534.33	530.91	527.48
Calculated composition				
ME (kcal/kg)	3080	3080	3080	3080
NE (kcal/kg)	2436	2442	2447	2452
Dry matter %	90.5	90.6	90.7	90.8
Crude protein %	22.4	22.4	22.3	22.3
Starch-protein ratio	1.825	1.745	1.672	1.591
T.Dig.Lys.Poult %	1.14	1.14	1.14	1.14
T.Dig.Met.Poult %	0.515	0.52	0.525	0.531
T.Dig.M+C.Poult %	0.863	0.863	0.863	0.863
T.Dig.Thr.Poult %	0.764	0.764	0.764	0.764
T.Dig.Iso.Poult %	0.773	0.773	0.773	0.773
T.Dig.Leu.Poult %	1.405	1.398	1.391	1.384
T.Dig.Trp.Poult %	0.233	0.233	0.233	0.232
T.Dig.Arg.Poult %	1.235	1.24	1.246	1.251
T.Dig.His.Poult %	0.48	0.477	0.474	0.472
T.Dig.Val.Poult %	0.885	0.885	0.885	0.885
Crude fat %	5.082	5.794	6.506	7.218
Crude fibre %	3.275	3.563	3.851	4.139
Starch %	40.9	39.1	37.3	35.5
Calcium %	0.9	0.9	0.9	0.9
Av. Phos %	0.45	0.45	0.45	0.45
Total Phos %	0.475	0.485	0.496	0.506
Sodium %	0.19	0.19	0.19	0.19
Chloride %	0.25	0.25	0.25	0.25
Potassium %	0.739	0.761	0.782	0.803
Na+K-Cl mEq/kg	201	206	212	217

[1]Vitamin concentrate supplied per kilogram of diet: retinol, 12000 IU; cholecalciferol, 5000 IU; tocopheryl acetate, 75 mg, menadione, 3 mg; thiamine, 3 mg; riboflavin, 8 mg; niacin, 55 mg; pantothenate, 13 mg; pyridoxine, 5 mg; folate, 2 mg; cyanocobalamin, 16 μg; biotin, 200 μg; cereal-based carrier, 149 mg; mineral oil, 2.5 mg. Trace mineral concentrate supplied per kilogram of diet: Cu (sulphate), 16 mg; Fe (sulphate), 40 mg; I (iodide), 1.25 mg; Se (selenate), 0.3 mg; Mn (sulphate and oxide), 120 mg; Zn (sulphate and oxide), 100 mg; cereal-based carrier, 128 mg; mineral oil, 3.75 mg.

Table 4. Compositions and calculated nutrient specifications in finisher diets

Ingredients %	No barley	Barley 15%	Barley 22.5%	Barley 30%
Wheat 14% CP – 3200 ME	71.345	52.765	43.475	34.185
Soybean meal	12.647	15.101	16.328	17.556
Canola seeds	5.000	5.000	5.000	5.000
Canola exp 36/9	4.000	4.000	4.000	4.000
Meat meal 55%	2.993	2.641	2.465	2.289
Canola oil	1.937	3.439	4.191	4.942
Lime fine 38%	0.746	0.790	0.812	0.833
Lysine HCL	0.346	0.295	0.270	0.245
Sodium bicarbonate	0.288	0.239	0.214	0.190
Vit/Min Premix	0.200	0.200	0.200	0.200
Dl-methionine	0.178	0.196	0.205	0.214
Salt	0.131	0.154	0.166	0.178
L-Threonine	0.105	0.094	0.089	0.084
Choline chloride	0.050	0.050	0.050	0.050
Axtra phy 10000	0.013	0.013	0.013	0.013
Xylanase	0.065	0.065	0.065	0.065
Barley 11% CP – 2850 ME	-	15.000	22.500	30.000
Cost ($/Tonne)	533.09	526.24	522.82	519.39
Calculated composition				
ME (kcal/kg)	3170	3170	3170	3170
NE (kcal/kg)	2525	2535	2541	2546
Dry matter %	90.5	90.7	90.8	90.8
Crude protein %	20.4	20.4	20.3	20.3
Starch-protein ratio	2.112	1.936	1.857	1.768
T.Dig.Lys.Poult %	1.021	1.021	1.021	1.021
T.Dig.Met.Poult %	0.465	0.476	0.481	0.486
T.Dig.M+C.Poult %	0.80	0.80	0.80	0.80
T.Dig.Thr.Poult %	0.681	0.681	0.681	0.681
T.Dig.Iso.Poult %	0.699	0.699	0.699	0.699
T.Dig.Leu.Poult %	1.285	1.27	1.263	1.256
T.Dig.Trp.Poult %	0.214	0.213	0.213	0.213
T.Dig.Arg.Poult %	1.094	1.105	1.11	1.115
T.Dig.His.Poult %	0.441	0.436	0.433	0.43
T.Dig.Val.Poult %	0.808	0.809	0.809	0.809
Crude fat %	6.099	7.523	8.235	8.947
Crude fibre %	3.422	3.998	4.286	4.574
Starch %	43.1	39.5	37.7	35.9
Calcium %	0.80	0.80	0.80	0.80
Av. Phos %	0.40	0.40	0.40	0.40
Total Phos %	0.413	0.434	0.445	0.455
Sodium %	0.19	0.19	0.19	0.19
Chloride %	0.23	0.23	0.23	0.23
Potassium %	0.666	0.709	0.73	0.751
Na+K-Cl mEq/kg	188	199	204	209

[1]Vitamin concentrate supplied per kilogram of diet: retinol, 12000 IU; cholecalciferol, 5000 IU; tocopheryl acetate, 75 mg, menadione, 3 mg; thiamine, 3 mg; riboflavin, 8 mg; niacin, 55 mg; pantothenate, 13 mg; pyridoxine, 5 mg; folate, 2 mg; cyanocobalamin, 16 μg; biotin, 200 μg; cereal-based carrier, 149 mg; mineral oil, 2.5 mg. Trace mineral concentrate supplied per kilogram of diet: Cu (sulphate), 16 mg; Fe (sulphate), 40 mg; I (iodide), 1.25 mg; Se (selenate), 0.3 mg; Mn (sulphate and oxide), 120 mg; Zn (sulphate and oxide), 100 mg; cereal-based carrier, 128 mg; mineral oil, 3.75 mg.

Table 5. Compositions and calculated nutrient specifications in withdrawal diets

Ingredients %	No barley	Barley 22.5%	Barley 30%	Barley 37.5%
Wheat 14% CP – 3200 ME	73.377	45.507	36.217	26.927
Soybean meal	11.232	14.914	16.141	17.369
Canola seeds	5.000	5.000	5.000	5.000
Canola exp 36/9	4.000	4.000	4.000	4.000
Meat meal 55% bb	2.302	1.773	1.597	1.421
Canola oil	2.012	4.266	5.017	5.769
Lime fine 38%	0.761	0.826	0.848	0.869
Lysine HCL	0.348	0.272	0.247	0.222
Sodium bicarbonate	0.294	0.220	0.195	0.171
Vit/Min Premix	0.200	0.200	0.200	0.200
Dl-Methionine	0.154	0.181	0.190	0.200
Salt	0.137	0.172	0.183	0.195
L-Threonine	0.100	0.084	0.079	0.073
Choline chloride	0.050	0.050	0.050	0.050
Axtra phy 10000	0.013	0.013	0.013	0.013
Xylanase	0.065	0.065	0.065	0.065
Barley 11% CP – 2850 ME	-	22.500	30.000	37.500
Cost ($/Tonne)	529.4	519.13	515.7	512.28
Calculated composition				
ME (kcal/kg)	3190	3190	3190	3190
NE (kcal/kg)	2544	2560	2565	2571
Dry matter %	90.5	90.7	90.8	90.9
Crude protein %	19.7	19.6	19.6	19.5
Starch-protein ratio	2.253	1.989	1.897	1.814
T.Dig.Lys.Poult %	0.979	0.979	0.979	0.979
T.Dig.Met.Poult %	0.434	0.45	0.455	0.46
T.Dig.M+C.Poult %	0.765	0.765	0.765	0.765
T.Dig.Thr.Poult %	0.653	0.653	0.653	0.653
T.Dig.Iso.Poult %	0.674	0.674	0.674	0.674
T.Dig.Leu.Poult %	1.242	1.22	1.213	1.206
T.Dig.Trp.Poult %	0.207	0.206	0.206	0.206
T.Dig.Arg.Poult %	1.041	1.057	1.063	1.068
T.Dig.His.Poult %	0.427	0.419	0.416	0.413
T.Dig.Val.Poult %	0.78	0.78	0.78	0.78
Crude fat %	6.128	8.264	8.976	9.688
Crude fibre %	3.391	4.255	4.543	4.831
Starch %	44.387	38.985	37.184	35.383
Calcium %	0.75	0.75	0.75	0.75
Av. Phos %	0.375	0.375	0.375	0.375
Total Phos %	0.383	0.414	0.424	0.435
Sodium %	0.19	0.19	0.19	0.19
Chloride %	0.23	0.23	0.23	0.23
Potassium %	0.64	0.704	0.726	0.747
Na+K-Cl mEq/kg	181	197	203	208

[1]Vitamin concentrate supplied per kilogram of diet: retinol, 12000 IU; cholecalciferol, 5000 IU; tocopheryl acetate, 75 mg, menadione, 3 mg; thiamine, 3 mg; riboflavin, 8 mg; niacin, 55 mg; pantothenate, 13 mg; pyridoxine, 5 mg; folate, 2 mg; cyanocobalamin, 16 μg; biotin, 200 μg; cereal-based carrier, 149 mg; mineral oil, 2.5 mg. Trace mineral concentrate supplied per kilogram of diet: Cu (sulphate), 16 mg; Fe (sulphate), 40 mg; I (iodide), 1.25 mg; Se (selenate), 0.3 mg; Mn (sulphate and oxide), 120 mg; Zn (sulphate and oxide), 100 mg; cereal-based carrier, 128 mg; mineral oil, 3.75 mg.

Results

Table 6. Growth performance over the starter period (1-9 d)

Treatment		BW g/b	BW g/b	BWG g/b	FI g/b	FCR g/g
Barley %	**β-glucanase**	**Day 1**	**Day 9**	**Day 1-9**	**Day 1-9**	**Day 1-9**
0.0	No	40.0	259[a]	219[a]	236	1.081
0.0	Yes	40.9	260[a]	220[a]	232	1.057
0.0	No	40.1	255[a]	214[a]	234	1.094
0.0	Yes	40.2	260[a]	220[a]	237	1.079
7.5	No	40.2	257[a]	217[a]	233	1.077
7.5	Yes	40.1	258[a]	218[a]	231	1.062
15	No	40.0	237[b]	197[b]	224	1.145
15	Yes	40.2	257[a]	217[a]	230	1.059
	SEM	0.409	3.43	3.28	2.96	0.016
Main effects						
Barley %						
0.0		40.3	259[a]	219[a]	234[a]	1.069
0.0		40.2	257[a]	217[a]	236[a]	1.086
7.5		40.0	257[a]	217[a]	232[a]	1.069
15		40.2	247[b]	207[b]	227[b]	1.102
	SEM	0.289	2.42	2.31	2.09	0.011
β-glucanase						
No		40.2	252[b]	212[b]	232	1.099[a]
Yes		40.1	259[a]	219[a]	233	1.064[b]
	SEM	0.201	1.81	1.63	1.48	0.008
Source of variation *(P-value)*						
Barley		0.606	0.003	0.002	0.027	0.117
β-glucanase		0.474	0.007	0.004	0.796	0.002
Barley × β-glucanase		0.517	0.025	0.018	0.372	0.076

Each value for each treatment represents the mean of six replicates of 18 birds each.
[a-b] Means within a column not sharing a superscript differ significantly at the P < 0.05 level for the treatment effects and at the P level shown for the main effects.

The interactive effects of barley inclusion and β-glucanase on the performance of broiler chickens over the starter period is presented in Table 6. Barley inclusion at 7.5% did not have any negative effect on bodyweight or feed intake (P > 0.05). Barley inclusion at 15% without added β-glucanase decreased bodyweight gain by about 8%, however, β-glucanase supplementation restored this lower bodyweight gain at high barley inclusion, resulting in a significant barley x β-glucanase interaction (P < 0.05). No significant effect of barley inclusion was detected on FCR, while β-glucanase supplementation improved FCR by 3.5 points (P < 0.01). This FCR improvement was more pronounced in high barley diets (8.6 points), creating a tendency (P = 0.076) for barley x β-glucanase interaction.

Table 7. Growth performance over the grower period (9-23 d)

Treatment		BW g/b	BWG g/b	FI g/b	FCR g/g
Barley %	**β-glucanase**	**Day 23**	**Day 9-23**	**Day 9-23**	**Day 9-23**
0.0	No	1230	972	1186	1.221
0.0	Yes	1225	965	1159	1.201
7.5	No	1220	965	1150	1.191
7.5	Yes	1264	1004	1174	1.169
15	No	1226	969	1140	1.177
15	Yes	1259	1001	1156	1.155
22.5	No	1202	965	1121	1.162
22.5	Yes	1241	984	1168	1.187
	SEM	15.16	13.22	21.21	0.018
Main effects					
Barley %					
0.0		1228	969	1173	1.211
7.5		1242	984	1162	1.180
15		1242	985	1148	1.166
22.5		1221	974	1144	1.175
	SEM	10.71	9.35	15.13	0.013
β-glucanase					
No		1220[b]	968[b]	1149	1.188
Yes		1247[a]	988[a]	1164	1.178
	SEM	7.58	6.61	10.63	0.009
Source of variation *(P-value)*					
Barley		0.424	0.531	0.533	0.081
β-glucanase		0.014	0.032	0.330	0.449
Barley × β-glucanase		0.374	0.337	0.379	0.471

Each value for each treatment represents the mean of six replicates of 18 birds each.
[a-b] Means within a column not sharing a superscript differ significantly at the P < 0.05 level for the treatment effects and at the P level shown for the main effects.

Over the grower period, barley inclusion had no effect on bodyweight and feed consumption but tended (P = 0.081) to improved FCR, particularly when added at 15% (Table 7). Addition of β-glucanase increased (P < 0.05) bodyweights by an average of 27 g/bird (2.2%).

Table 8. Growth performance over the finisher period (23-35 d)

Treatment		BW g/b	BWG g/b	FI g/b	FCR g/g
Barley %	**β-glucanase**	**Day 35**	**Day 23-35**	**Day 23-35**	**Day 23-35**
0.0	No	2523	1293	1861	1.440
0.0	Yes	2520	1295	1837	1.419
15	No	2517	1296	1831	1.412
15	Yes	2594	1330	1883	1.416
22.5	No	2591	1366	1895	1.389
22.5	Yes	2609	1350	1871	1.385
30	No	2544	1342	1859	1.386
30	Yes	2581	1341	1874	1.397
	SEM	27.06	18.06	23.94	0.013
Main effects					
Barley %					
0.0		2522^{c}	1294^{c}	1849	1.429^{a}
15		2555^{bc}	1313^{bc}	1857	1.414^{ab}
22.5		2600^{a}	1358^{a}	1883	1.387^{b}
30		2563^{ab}	1341^{ab}	1866	1.392^{b}
	SEM	18.99	12.77	16.93	0.009
β-glucanase					
No		2544	1324	1862	1.407
Yes		2576	1329	1866	1.404
	SEM	13.53	9.03	11.97	0.006
Source of variation *(P-value)*					
Barley		0.049	0.004	0.531	0.010
β-glucanase		0.097	0.701	0.796	0.798
Barley × β-glucanase		0.509	0.583	0.335	0.654

Each value for each treatment represents the mean of six replicates of 18 birds each.
$^{a-c}$ Means within a column not sharing a superscript differ significantly at the P < 0.05 level for the treatment effects and at the P level shown for the main effects.

According to the data presented in Table 8, on day 35, barley inclusion at 15% and 22.5% increased bodyweight compared with no barley diets (P < 0.05). There was no significant effect of β-glucanase alone or as an interaction with barley inclusion, but the enzyme, numerically, improved bodyweight gain when barley was included at 15% or 30%, but had no marked effect at 0% or 22.5% barley inclusion. Barley inclusion at 22.5% and 30%, regardless of β-glucanase addition, improved FCR over the finisher period (23-35 d; P < 0.01).

Table 9. Growth performance over the withdrawal period (35-42 d)

Treatment		BW g/b	BWG g/b	FI g/b	FCR g/g
Barley %	**β-glucanase**	**Day 42**	**Day 35-42**	**Day 35-42**	**Day 35-42**
0.0	No	3184	661	1034	1.566
0.0	Yes	3193	672	1028	1.530
22.5	No	3205	688	1048	1.525
22.5	Yes	3287	694	1040	1.500
30	No	3304	712	1059	1.487
30	Yes	3313	703	1030	1.467
37.5	No	3219	675	1048	1.569
37.5	Yes	3290	708	1053	1.487
	SEM	32.45	15.73	13.80	0.031
Main effects					
Barley %					
0.0		3188^{b}	667	1031	1.548
22.5		3246^{ab}	691	1044	1.512
30		3308^{a}	708	1044	1.477
37.5		3254^{a}	691	1050	1.528
	SEM	22.94	11.12	9.75	0.022
β-glucanase					
No		3228	684	1047	1.537
Yes		3271	692	1038	1.496
	SEM	16.22	7.86	6.90	0.015
Source of variation *(P-value)*					
Barley		0.007	0.091	0.558	0.151
β-glucanase		0.070	0.361	0.329	0.071
Barley × β-glucanase		0.533	0.601	0.676	0.748

Each value for each treatment represents the mean of six replicates of 18 birds each.
$^{a-b}$ Means within a column not sharing a superscript differ significantly at the P < 0.05 level for the treatment effects and at the P level shown for the main effects.

On day 42, birds fed diets with barley at 30% and 37.5% recorded a higher bodyweight than the birds fed no barley diets (P < 0.01). β-glucanase supplementation tended (P = 0.07) to improve final bodyweights by an average of 43 g/bird. Feed intake and feed conversion were neither affected by barley or β-glucanase inclusion during the withdrawal period (35-42 d; P > 0.05).

Table 10. Growth performance over the growth period (1-42 d) and feed cost per kg of final bodyweight

Treatment		BW g/b	BWG g/b	FI g/b	FCR g/g	BWc FCR	Feed cost
Barley %	**β-glucanase**	**Day 42**	**Day 1-42**	**Day 1-42**	**Day 1-42**	**Day 1-42**	**$/kg live BW**
0.0	No	3184	3144	4318	1.374	1.376	$0.7335
0.0	Yes	3193	3152	4256	1.350	1.350	$0.7244
Low	No	3205	3164	4263	1.347	1.345	$0.7107
Low	Yes	3287	3247	4334	1.335	1.316	$0.7070
Medium	No	3304	3264	4327	1.326	1.304	$0.6952
Medium	Yes	3313	3273	4289	1.310	1.287	$0.6894
High	No	3219	3178	4253	1.338	1.334	$0.6968
High	Yes	3290	3249	4324	1.331	1.312	$0.6956
	SEM	32.45	32.27	45.12	0.009	0.012	0.0049
Main effects							
Barley %							
0.0		3188^{b}	3148^{b}	4287	1.362^{a}	1.363^{a}	$0.7290a
Low		3246^{ab}	3206^{ab}	4298	1.341^{b}	1.331^{b}	$0.7089b
Medium		3308^{a}	3268^{a}	4308	1.318^{c}	1.295^{c}	$0.6923c
High		3254^{a}	3214^{a}	4288	1.335^{bc}	1.323^{b}	$0.6962c
	SEM	22.94	22.81	31.90	0.006	0.008	0.0034
β-glucanase							
No		3228	3188	4290	1.346^{a}	1.340^{a}	$0.7091
Yes		3271	3231	4300	1.331^{b}	1.316^{b}	$0.7041
	SEM	16.22	16.13	22.56	0.004	0.006	0.0024
Source of variation *(P-value)*							
Barley		0.007	0.007	0.963	0.004	<.001	<.001
β-glucanase		0.070	0.067	0.752	0.028	0.012	0.161
Barley × β-glucanase		0.533	0.521	0.313	0.860	0.970	0.874

Each value for each treatment represents the mean of six replicates of 18 birds each.
$^{a\text{-}c}$ Means within a column not sharing a superscript differ significantly at the P < 0.05 level for the treatment effects and at the P level shown for the main effects.

Table 10 summerasies the effects of dietray treatments on broiler performance over the production period (1-42 d). Birds fed diets with medium and high barley levels had higher bodyweight gain than birds offered no-barley diets (P < 0.01). Addition of β-glucanase to the diets tended to improve bodyweight gain across all treatments (P = 0.067). A greater response to β-glucanase in increasing bodyweight gain was observed in birds fed the low (3164 vs 3247 g/bird) and high (3178 vs 3249 g/bird) barley diets, however, the magnitude of these differences was not large enough to result in a statistically significant interaction between barley inclusion and β-glucanase supplementation. Barley inclusion at low, medium, and high levels improved final FCR by 2.1, 4.4 and 2.7 points compared with no-barley diets (P < 0.01), and when corrected for bodyweight these improvements further increased to 3.2, 6.8 and 4.0 FCR points, respectively. There was a statistically significant improvement in both FCR and bodyweight-corrected FCR in response to β-glucanase inclusion over the production period (P < 0.05).

The data on feed cost per kg of live body weight is presented in Table 10. The highest and lowest feed cost per kg BW was calculated in birds fed the control (no-barley) diets without β-glucanase and medium barley diets with β-glucanase ($0.7335 vs $0.6894; 6.4% lower).

Table 11. Carcass yield (g/100 g live BW), woody breast and white striping scores, and distal ileal water content on day 42

Treatment		g/100 g live BW				Breast score		DI[1] water CON
Barley %	**β-glucanase**	**P. Major**	**P. Minor**	**Leg quarter**	**Fat pad**	**WB**	**WS**	**g/100 g Digesta**
0.0	No	16.8	3.34	21.3	1.16	0.875	0.667	58.5
0.0	Yes	17.0	3.35	21.6	1.14	1.042	0.667	58.4
Low	No	17.2	3.38	21.5	1.16	0.750	0.667	64.2
Low	Yes	17.4	3.40	21.3	1.22	1.000	0.625	61.8
Medium	No	18.5	3.44	21.2	1.13	1.167	0.875	63.5
Medium	Yes	17.8	3.56	21.3	1.26	1.042	0.667	61.0
High	No	17.3	3.45	21.3	1.20	0.750	0.625	64.2
High	Yes	17.7	3.45	21.0	1.16	1.125	0.417	62.6
	SEM	0.32	0.064	0.24	0.059	0.250	0.205	1.54
Main effects								
Barley %								
0.0		16.9b	3.35	21.5	1.15	0.958	0.667	58.5b
Low		17.3b	3.39	21.4	1.19	0.875	0.646	63.0a
Medium		18.1a	3.50	21.3	1.20	1.104	0.771	62.2a
High		17.5ab	3.45	21.2	1.18	0.938	0.521	63.4a
	SEM	0.226	0.045	0.17	0.042	0.177	0.145	1.11
β-glucanase								
No		17.4	3.40	21.3	1.16	0.885	0.708	62.6
Yes		17.5	3.44	21.3	1.19	1.052	0.594	60.9
	SEM	0.16	0.032	0.12	0.030	0.125	0.102	0.782
Source of variation *(P-value)*								
Barley		0.004	0.099	0.575	0.876	0.824	0.683	0.011
β-glucanase		0.777	0.399	0.788	0.468	0.351	0.433	0.146
Barley × β-glucanase		0.300	0.787	0.811	0.427	0.781	0.933	0.846

Each value for each treatment represents the mean of four birds per replicate, and six replicates per treatment.
[a-c] Means within a column not sharing a superscript differ significantly at the P < 0.05 level for the treatment effects and at the P level shown for the main effects.
[1] Distal ileal digesta water content

Barley inclusion at medium levels significantly (P < 0.01) increased breast major muscle yield and tended (P = 0.099) to increase breast minor muscle yield. Leg quarter and fat pad percentages, and woody breast and white striping scores, were neither affected by barley inclusion nor β-glucanase addition (P > 0.05).

Barley, regardless of inclusion rate, increased distal ileal digesta water content by about 8-10% compared with no-barley diets (P < 0.05). β-glucanase supplementation non-significantly decreased digesta water content by about 4%.

Table 12. Correlation analysis between FCRs and starch-to-protein ratios (analysed) and net energy (calculated) of the control diets without β-glucanase at each growing phase

FCR	FCR by ST:CP		FCR by net energy	
	Correlation	Significance	Correlation	Significance
FCR 1-9 day	-0.42	0.042	0.41	0.044
FCR 9-23 day	0.44	0.029	-0.44	0.028
FCR 23-35 day	0.50	0.011	-0.51	0.016
FCR 35-42 day	0.10	0.623	-0.10	0.658
FCR 1-42 day	0.50	0.012	-0.50	0.012

As barley has less starch and thus lower metabolisable energy compared with wheat, increasing barley inclusion decreased the starch-to-protein ratio (ST:CP), and increased the net energy (NE) of the corresponding diets due to higher supplemental oil. FCR values, except for the starter period, were positively correlated with ST:CP ratios ($P < 0.05$). There were also negative correlations between FCR values and diet NE in grower, finisher, and the entire production (1-42 d) period ($P < 0.05$). These correlation analyses indicate that a lower ST:CP ratio and higher NE content in barley diets could partly account for the improved FCR of birds fed such diets.

Pellet durability index (PDI)

Barley inclusion, regardless of inclusion level, reduced pellet durability compared with control diets. The PDI levels dropped to below 40 when the inclusion rate of barley increased in finisher and withdrawal feed.

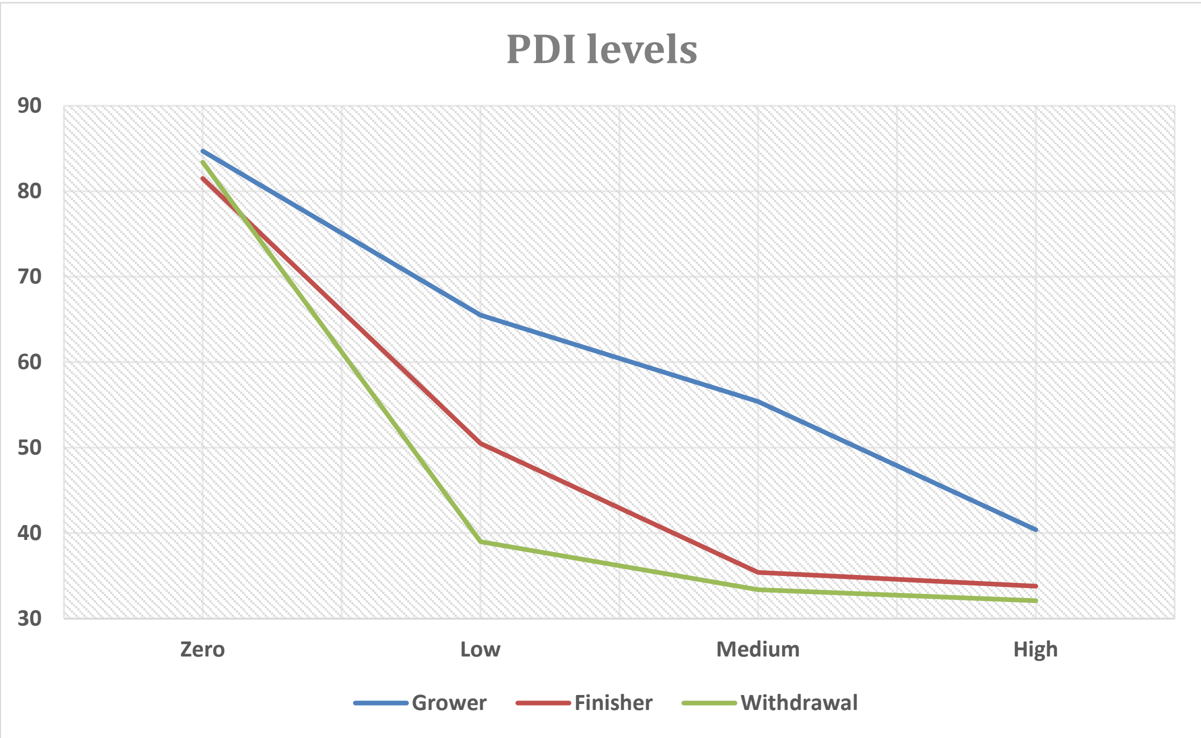

Figure 3. Pellet quality index levels of diets determined in triplicate for each phase

Conclusion

The results observed in this study suggest that barley can be included at a level up to 7.5% in broiler starter diets without compromising growth performance. At higher inclusion levels, diets should be supplemented with β-glucanase to mitigate the performance loss in young birds. Increasing barley levels to 22.5% in grower diets can slightly decrease growth rate but has no effects on feed conversion. β-glucanase supplementation can completely restore the bodyweight gain loss due to high barley levels and improves FCR. Stepping up barley levels to 30% in finisher and 37.5% in withdrawal diets not only does not compromise growth performance, but such high levels could improve both bodyweight gain and FCR. β-glucanase supplementation at each level of barley inclusion improves bodyweight gain and FCR, however, this improvement is more pronounced at low and high barley inclusions. Under the conditions of the present study, it seems that application of an incremental program is an effective approach to optimise barley inclusion in broiler chickens' diets, especially when diets are formulated to digestible amino acids and the lower ME content of barley is accounted for in formulations. Overall, birds fed the diets with medium levels of barley (7.5%, 15%, 22.5% and 30% in STR, GRW, FIN and WDRL, respectively) had the highest bodyweight gain and lowest FCR, indicating the importance of conditioning the gut and exposing the gut microbiota (priming microbiota) to any dietary changes at a young age.

The lower starch-to-protein ratio and higher net energy of barley diets may explain the higher bodyweights and lower FCR observed with high barley inclusion. In addition, as the wheat used in this study was a high-protein wheat (14%), the addition of barley to replace wheat also increased soybean meal inclusions in barley-included diets. Soybean meal is believed to have a better-balanced amino acid profile and be of higher quality compared with grains' protein. Thus, it is plausible that the differences in protein profile, particularly non-essential amino acids, between high barley diets and wheat-based diets, might also partly account for better productive performance of birds fed the high barley diets.

The cellulose and lignin content of barley (% of grain) is nearly twice that of wheat. The higher insoluble cellulose and lignin polysaccharides in barley diets could have stimulated the gizzard function and secretion of digestive enzymes and bile acids, resulting in better digestion and absorption of nutrients. In addition, lignin oligosaccharides can act as prebiotics to improve gut health and performance.

High barley inclusion increases digesta water content by about 8-10%, which can lead to high litter moisture and under commercial high-density rearing conditions may cause wet litter issues if the extra moisture is not removed by increased ventilation. β-glucanase supplementation of high barley diets can reduce about 30-40% of this increased moisture.

Low pellet durability can increase feed waste and birds' maintenance energy (10% PDI improvement represents about 14 kcal of effective caloric value), resulting in lower bodyweight and higher FCR. However, the low PDI values determined for barley diets in this study did not impact productive traits, or the impact was moderate and masked out by the superior performance of birds fed the barley diets, as discussed earlier.

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