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# Measurement of Acid-Binding Capacity for Poultry Feedstuffs in Deionized and Magnetized Water

Research Article

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## ABSTRACT

Acid-binding capacity (ABC) of a feed is the amount of acid required to reduce the pH of feed to a special level such as 3. All poultry feed ingredients used in this study were collected from feed mills in Iran. The pH and ABC were determined using the standard methods in deionized and magnetized water at room and body temperatures. The pH of most feed ingredients was raised in magnetized water as compared to deionized (untreated water). The pH of most feed ingredients especially organic acids was decreased in warm water. Energy sources accompanied by synthetic amino acids and common salt and some additives such as prebiotic and zeolite had the lowest values of ABC (less that 400 mEq/kg). Protein sources and some supplements and additives had average ABC of about 400-1000 mEq/kg, and some vitamins and minerals had high level of ABC (more than 1000 mEq/kg) among all ingredients. Calcium carbonate and sodium bicarbonate, along with ammonium formate and calcium propionate had the highest ABC values among all ingredients. Pelleting did not show any pronounced impact on pH or ABC of whole diet; while extruding did not alter ABC of soybean but significantly increased ABC of flaxseed. These results give indication that the type of feed ingredient, or processing and solution used for ABC evaluation, especially magnetizing treatment and ambient temperature, are determining factors for ABC of feedstuffs.

**KEY WORDS** acid-binding capacity, feedstuffs, poultry, magnetized water.

## INTRODUCTION

Chemical composition of feed ingredients and complete diets are of utmost importance for poultry nutritionists. Nowadays, it is well accepted that other physiochemical criteria such as particle size among others, deserve close consideration along with the composition. Acid-binding capacity (ABC) is a new launched concept among numerous other characteristics in this regard. The ABC of a feed is the amount of acid required to reduce the pH of feed to a special level (Jasaitis *et al*. 1987; Lawlor *et al*. 2005; Rynsburger, 2009). Due to the presence of various ingredients, characterized by different chemical composition, their corresponding ABC can be considerably different. For instance, Lawlor *et al.* (2005) and Rynsburger (2009) showed that mineral ingredients containing calcium had the highest ABC followed by protein ingredients, whereas cereal grains and other energy sources had the lowest. Feed type, ion content, and total ash are important factors influencing feed ABC (Jasaitis *et al*. 1987). Therefore, the formulated diets do not have the same ABC due to the presence of various ingredients. Thus, similarly to dietary electrolyte balance (DEB, DCAB or DCAD), ABC can be defined as a brand-new concept in poultry nutrition. Water as a medium for ABC measurement can be affected by environmental factors, and in particular magnetization. Noteworthy, it has been claimed that magnetic treatment of water might change the biophysical properties of water (Lin and Yotvat, 1990; Caia *et al.* 2009). Thus, along with the standard procedure of ABC measurement (Lawlor *et al.* 2005), we have paid attention to determine ABC of feedstuffs in magnetic water and compared it to the same measurement in deionized water. In addition, since body temperature can affect ABC of feed ingredients in the gut canal, the same ABC was examined at 41 ˚C which is the body temperature of chicken. The objective of this study was to establish a database for the ABC of commonly used ingredients in broiler's feed in various conditions for possible future use in feed formulation.

## MATERIALS AND METHODS

All poultry feed ingredients have been collected from feed mills in Iran. Soybean meal, corn, wheat, barley, limestone and all other samples with a grain or granule shape were ground using a 1 mm screen. All remaining samples were not ground because of their already fine nature.

The pH of each ingredient was determined by suspending 0.5 gram of ground dry matter sample in 50 mL of deionized water by continuous stirring using a stir plate at room temperature. The pH of the solution was recorded once the pH had been stabilized for 3 minutes (stable to ±0.01). The ABC was determined using the method of Jasaitis *et al.* (1987) as modified by Lawlor *et al.* (2005). Titrations were performed by addition of acid (0.1 N HC1) or base (0.1 N NaOH) in variable increments until the pH reached 3. Total volume of acid or base added to each sample was recorded and then multiplied by the normality to calculate titratable acidity and alkalinity (Jasaitis *et al.* 1987). The ABC is expressed as the amount of hydrochloric acid in milliequivalents (mEq) needed to decrease the pH of 1 kilogram of sample to pH 3. However, the ABC for acids is expressed as a negative number due to the NaOH that is used for its measurement and the increase of pH to 3. Rynsburger (2009) conducted the tests for pH and ABC twice for each sample, whereas in this study we repeated the test four times to decrease the variation achieving thus more precise data.

The water used in this study was high-level deionized water which was produced by a Direct-Q Millipore System. Then, this deionized water was magnetized as follows: the static magnetic field was produced with AQUA CORRECT device (Figure 1). The equipment, made in Germany, had a coaxial static magnetic system of 6500G field strength. A certain volume of purified water was circulated in a close loop from a closed tank through PVC tubing linked to a pump. Therefore, solution could pass through the field many times in a closed cycle. The flow rate was settled at around 36 L/min.


**Figure 1** Magnetizing apparatus used in the study

All data were analyzed using the General Linear Model procedure of the Statistical Analysis System (SAS, 2004). Tukey's Studentized Range (HSD) test was used to compare means. All statements of significance were based on probability of P<0.05. The model used for a factorial experiment with two factors A (deionized or magnetized water) and B (21 or 41 ˚C for water temperature) was:

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + e_{ijk}$$

i= 1,…, a.
j= 1,…, b.
k= 1,…, n.

Where:
$y_{ijk}$: observation k in level i of A and level j of B.
$\mu$: the overall mean.
$A_i$: the effect of level i of A.
$B_j$: the effect of level j of B.
$(AB)_{ij}$: the effect of the interaction of level i of factor A with level j of factor B.
$e_{ijk}$: random error.
a: number of levels of factor A.
b: number of levels of factor B.
n: number of observations for each A × B combination.

## RESULTS AND DISCUSSION

The pH determination for various groups of feed ingredients are presented in Tables 1 to 6. The pH of most feed ingredients has been raised in magnetized water when compared to deionized (untreated water). The reason for this is not clear but it may be related to the findings of Holysz *et al.* (2002), who reported that zeta potential as a function of the pH solution was changed due to magnetic field treatment. The significance of zeta potential is that its value can be linked to the stability of colloidal dispersions like in multivitamin syrup.

**Table 1** Effect of magnetization and temperature of water on pH of cereal grains, their by-products, oil and fat.

| Effects | Corn | Wheat | Barley | Wheat bran | Rice bran | Vegetable oil | Fat powder |
|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | |
| Deionized | 5.76$^{b}$ | 5.88$^{b}$ | 6.10$^{b}$ | 5.67 | 6.29$^{b}$ | 5.27$^{b}$ | 5.73$^{b}$ |
| Magnetized | 6.69$^{a}$ | 6.67$^{a}$ | 7.02$^{a}$ | 6.78 | 7.07$^{a}$ | 6.92$^{a}$ | 6.54$^{a}$ |
| ±SEM | 0.030 | 0.056 | 0.135 | 0.365 | 0.048 | 0.101 | 0.093 |
| P-value | < 0.0001 | < 0.0001 | 0.0013 | 0.052 | < 0.0001 | < 0.0001 | 0.0003 |
| **Temperature** | | | | | | | |
| 21 ˚C | 6.68$^{a}$ | 6.70$^{a}$ | 6.50 | 5.98 | 6.90$^{a}$ | 6.43$^{a}$ | 6.43$^{a}$ |
| 41 ˚C | 5.89$^{b}$ | 5.84$^{b}$ | 6.63 | 6.47 | 6.45$^{b}$ | 5.77$^{b}$ | 5.84$^{b}$ |
| ±SEM | 0.028 | 0.056 | 0.135 | 0.341 | 0.048 | 0.101 | 0.093 |
| P-value | < 0.0001 | < 0.0001 | 0.515 | 0.357 | 0.0001 | 0.001 | 0.002 |
| **Interactions** | | | | | | | |
| Deionized 21 ˚C | 6.31$^{b}$ | 6.39 | 6.23 | 5.53 | 6.44 | 6.29$^{b}$ | 6.63$^{ab}$ |
| Deionized 41 ˚C | 5.36$^{c}$ | 5.38 | 5.97 | 5.81 | 6.14 | 5.26$^{c}$ | 4.82$^{c}$ |
| Magnetized 21 ˚C | 7.05$^{a}$ | 7.02 | 6.76 | 6.44 | 7.37 | 7.28$^{a}$ | 6.86$^{a}$ |
| Magnetized 41 ˚C | 6.42$^{b}$ | 6.31 | 7.28 | 7.13 | 6.77 | 6.57$^{b}$ | 6.23$^{b}$ |
| ±SEM | 0.046 | 0.080 | 0.191 | 0.517 | 0.073 | 0.143 | 0.133 |
| P-value | 0.003 | 0.083 | 0.073 | 0.691 | 0.060 | < 0.0001 | < 0.0001 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

**Table 2** Effect of magnetization and temperature of water on pH of oilseeds and their by-products

| Effects | Full fat soybean | Extruded soybean | Soybean meal | Flaxseed | Extruded flaxseed | Cottonseed meal | Canola meal | Sunflower meal | Safflower meal |
|---|---|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | | | |
| Deionized | 6.12$^{b}$ | 6.97 | 6.48$^{b}$ | 5.90$^{b}$ | 6.06$^{b}$ | 5.88$^{b}$ | 5.17$^{b}$ | 5.81$^{b}$ | 5.23$^{b}$ |
| Magnetized | 6.61$^{a}$ | 7.23 | 6.87$^{a}$ | 6.65$^{a}$ | 7.28$^{a}$ | 6.92$^{a}$ | 6.39$^{a}$ | 6.44$^{a}$ | 6.79$^{a}$ |
| ±SEM | 0.117 | 0.109 | 0.036 | 0.072 | 0.079 | 0.020 | 0.063 | 0.065 | 0.051 |
| P-value | 0.013 | 0.121 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 | 0.0001 | < 0.0001 |
| **Temperature** | | | | | | | | | |
| 21 ˚C | 6.31 | 7.32$^{a}$ | 7.00$^{a}$ | 6.98$^{a}$ | 7.02$^{a}$ | 6.53$^{a}$ | 5.88 | 6.55$^{a}$ | 5.96 |
| 41 ˚C | 6.42 | 6.88$^{b}$ | 6.34$^{b}$ | 5.57$^{b}$ | 6.32$^{b}$ | 6.26$^{b}$ | 5.68 | 5.71$^{b}$ | 6.07 |
| ±SEM | 0.117 | 0.109 | 0.034 | 0.072 | 0.079 | 0.020 | 0.067 | 0.065 | 0.051 |
| P-value | 0.522 | 0.023 | < 0.0001 | < 0.0001 | 0.0001 | < 0.0001 | 0.050 | < 0.0001 | 0.198 |
| **Interactions** | | | | | | | | | |
| Deionized 21 ˚C | 5.93 | 7.23 | 6.84 | 6.92$^{a}$ | 6.36$^{b}$ | 6.33$^{b}$ | 5.53$^{c}$ | 6.36$^{b}$ | 5.26 |
| Deionized 41 ˚C | 6.31 | 6.71 | 6.12 | 4.88$^{c}$ | 5.75$^{c}$ | 5.43$^{c}$ | 5.41$^{c}$ | 5.26$^{b}$ | 5.21 |
| Magnetized 21 ˚C | 6.70 | 7.41 | 7.16 | 7.04$^{a}$ | 7.68$^{a}$ | 6.74$^{b}$ | 6.83$^{a}$ | 6.75$^{a}$ | 6.67 |
| Magnetized 41 ˚C | 6.52 | 7.06 | 6.57 | 6.27$^{b}$ | 6.88$^{b}$ | 7.10$^{a}$ | 5.96$^{b}$ | 6.13$^{b}$ | 6.92 |
| ±SEM | 0.165 | 0.155 | 0.055 | 0.102 | 0.112 | 0.031 | 0.095 | 0.093 | 0.075 |
| P-value | 0.114 | 0.584 | 0.233 | 0.0003 | 0.041 | < 0.0001 | < 0.0001 | 0.032 | 0.075 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

**Table 3** Effect of magnetization and temperature of water on pH of some protein and amino acid sources

| Effects | Corn gluten meal | Fish meal | Meat meal | L-lysine HCl | L-threonine | DL-methionine |
|---|---|---|---|---|---|---|
| **Water** | | | | | | |
| Deionized | 5.09$^{b}$ | 5.12$^{b}$ | 5.57$^{b}$ | 5.82$^{b}$ | 4.96$^{b}$ | 5.65$^{b}$ |
| Magnetized | 5.47$^{a}$ | 6.09$^{a}$ | 6.23$^{a}$ | 6.36$^{a}$ | 6.41$^{a}$ | 6.77$^{a}$ |
| ±SEM | 0.103 | 0.070 | 0.050 | 0.070 | 0.051 | 0.123 |
| P-value | 0.033 | < 0.0001 | < 0.0001 | 0.0005 | < 0.0001 | 0.0001 |
| **Temperature** | | | | | | |
| 21 ˚C | 5.33 | 5.51 | 5.88 | 6.15 | 6.04$^{a}$ | 6.34 |
| 41 ˚C | 5.22 | 5.70 | 5.93 | 6.03 | 5.33$^{b}$ | 6.09 |
| ±SEM | 0.103 | 0.065 | 0.050 | 0.075 | 0.051 | 0.123 |
| P-value | 0.480 | 0.080 | 0.475 | 0.284 | < 0.0001 | 0.175 |
| **Interactions** | | | | | | |
| Deionized 21 ˚C | 5.24 | 4.94 | 6.09$^{ab}$ | 5.88$^{b}$ | 5.58$^{b}$ | 5.67$^{b}$ |
| Deionized 41 ˚C | 4.94 | 5.29 | 5.05$^{c}$ | 5.75$^{b}$ | 4.35$^{c}$ | 5.64$^{b}$ |
| Magnetized 21 ˚C | 5.42 | 6.07 | 5.66$^{b}$ | 6.41$^{a}$ | 6.51$^{a}$ | 7.01$^{a}$ |
| Magnetized 41 ˚C | 5.51 | 6.11 | 6.81$^{a}$ | 6.31$^{a}$ | 6.32$^{a}$ | 6.54$^{a}$ |
| ±SEM | 0.146 | 0.107 | 0.071 | 0.106 | 0.073 | 0.179 |
| P-value | 0.219 | 0.156 | < 0.0001 | 0.047 | < 0.0001 | 0.235 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

**Table 4** Effect of magnetization and temperature of water on pH of some vitamin and mineral sources

| Effects | Vitamin premix | Vitamin $D_3$ | Vitamin E + Se | Choline chloride | Mineral premix | NaCl | Sodium bicarbonate | Calcium carbonate | Oyster shell | Dicalcium phosphate | Monocalcium phosphate |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | | | | | |
| Deionized | 5.53 | 6.36$^{b}$ | 6.31$^{b}$ | 6.38$^{b}$ | 5.25$^{b}$ | 6.48$^{b}$ | 8.03$^{b}$ | 8.60 | 7.83$^{b}$ | 4.38$^{b}$ | 3.65 |
| Magnetized | 5.61 | 7.26$^{a}$ | 7.15$^{a}$ | 6.89$^{a}$ | 5.75$^{a}$ | 6.93$^{a}$ | 8.41$^{a}$ | 8.35 | 8.21$^{a}$ | 4.45$^{a}$ | 3.73 |
| ±SEM | 0.041 | 0.061 | 0.031 | 0.048 | 0.107 | 0.016 | 0.048 | 0.131 | 0.086 | 0.017 | 0.042 |
| P-value | 0.216 | < 0.0001 | < 0.0001 | < 0.0001 | 0.0076 | < 0.0001 | 0.0006 | 0.203 | 0.014 | 0.0024 | 0.233 |
| **Temperature** | | | | | | | | | | | |
| 21 °C | 5.72$^{a}$ | 7.02$^{a}$ | 7.06$^{a}$ | 6.94$^{a}$ | 5.60 | 6.87$^{a}$ | 8.50$^{a}$ | 8.96$^{a}$ | 8.65$^{a}$ | 4.51$^{a}$ | 3.84$^{a}$ |
| 41 °C | 5.41$^{b}$ | 6.59$^{b}$ | 6.39$^{b}$ | 6.33$^{b}$ | 5.40 | 6.55$^{b}$ | 7.94$^{b}$ | 7.99$^{b}$ | 7.39$^{b}$ | 4.30$^{b}$ | 3.54$^{b}$ |
| ±SEM | 0.043 | 0.061 | 0.031 | 0.048 | 0.115 | 0.015 | 0.048 | 0.140 | 0.086 | 0.018 | 0.042 |
| P-value | 0.0003 | 0.0012 | < 0.0001 | < 0.0001 | 0.207 | < 0.0001 | < 0.0001 | 0.0004 | < 0.0001 | < 0.0001 | 0.0005 |
| **Interactions** | | | | | | | | | | | |
| Deionized 21 °C | 5.53$^{b}$ | 7.03$^{b}$ | 7.26$^{a}$ | 7.05$^{a}$ | 5.19 | 6.79$^{b}$ | 8.36$^{a}$ | 9.51$^{a}$ | 8.61$^{a}$ | 4.59$^{a}$ | 3.90$^{a}$ |
| Deionized 41 °C | 5.53$^{b}$ | 5.68$^{c}$ | 5.35$^{c}$ | 5.71$^{c}$ | 5.30 | 6.17$^{c}$ | 7.71$^{c}$ | 7.69$^{c}$ | 7.05$^{c}$ | 4.12$^{c}$ | 3.41$^{b}$ |
| Magnetized 21 °C | 5.92$^{a}$ | 7.02$^{b}$ | 6.87$^{b}$ | 6.83$^{b}$ | 6.01 | 6.95$^{a}$ | 8.65$^{a}$ | 8.41$^{b}$ | 8.69$^{a}$ | 4.43$^{b}$ | 3.79$^{a}$ |
| Magnetized 41 °C | 5.30$^{b}$ | 7.51$^{a}$ | 7.44$^{a}$ | 6.95$^{b}$ | 5.50 | 6.92$^{a}$ | 8.18$^{b}$ | 8.28$^{b}$ | 7.74$^{b}$ | 4.47$^{ab}$ | 3.67$^{ab}$ |
| ±SEM | 0.053 | 0.087 | 0.043 | 0.073 | 0.160 | 0.021 | 0.069 | 0.198 | 0.123 | 0.026 | 0.059 |
| P-value | 0.0003 | < 0.0001 | < 0.0001 | < 0.0001 | 0.068 | < 0.0001 | 0.221 | 0.0011 | 0.041 | < 0.0001 | 0.0108 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

**Table 5** Effect of magnetization and temperature of water on pH of some additives

| Effects | Bentonite | Zeolite | Whey powder | Yeast (*Saccharomyces cerevisiae*) | Prebiotic (Fermacto®) | Diclazuril | Maduramycin | Salinomycin |
|---|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | | |
| Deionized | 7.32$^{b}$ | 6.76$^{b}$ | 6.56 | 6.42 | 3.39 | 5.55$^{b}$ | 5.78$^{b}$ | 6.58$^{b}$ |
| Magnetized | 8.17$^{a}$ | 7.13$^{a}$ | 6.59 | 6.53 | 3.50 | 6.62$^{a}$ | 6.34$^{a}$ | 7.83$^{a}$ |
| ±SEM | 0.123 | 0.063 | 0.057 | 0.044 | 0.087 | 0.176 | 0.108 | 0.346 |
| P-value | 0.0012 | 0.0035 | 0.661 | 0.117 | 0.380 | 0.0027 | 0.0063 | 0.034 |
| **Temperature** | | | | | | | | |
| 21 °C | 8.26$^{a}$ | 7.38$^{a}$ | 6.67$^{a}$ | 6.63$^{a}$ | 3.69$^{a}$ | 6.38$^{a}$ | 6.02 | 7.14 |
| 41 °C | 7.23$^{b}$ | 6.51$^{b}$ | 6.48$^{b}$ | 6.33$^{b}$ | 3.21$^{b}$ | 5.78$^{b}$ | 6.10 | 7.27 |
| ±SEM | 0.123 | 0.063 | 0.057 | 0.044 | 0.087 | 0.176 | 0.108 | 0.346 |
| P-value | 0.0004 | < 0.0001 | 0.040 | 0.0014 | 0.004 | 0.044 | 0.614 | 0.787 |
| **Interactions** | | | | | | | | |
| Deionized 21 °C | 8.46$^{a}$ | 7.72$^{a}$ | 6.71$^{a}$ | 6.84$^{a}$ | 3.59 | 5.54$^{b}$ | 5.98$^{b}$ | 6.53 |
| Deionized 41 °C | 6.18$^{b}$ | 5.81$^{c}$ | 6.40$^{b}$ | 6.01$^{c}$ | 3.19 | 5.56$^{b}$ | 5.58$^{b}$ | 6.63 |
| Magnetized 21 °C | 8.06$^{a}$ | 7.05$^{b}$ | 6.94$^{a}$ | 6.42$^{b}$ | 3.87 | 7.20$^{a}$ | 6.06$^{ab}$ | 7.74 |
| Magnetized 41 °C | 8.29$^{a}$ | 7.21$^{b}$ | 6.24$^{b}$ | 6.65$^{ab}$ | 3.23 | 6.03$^{b}$ | 6.62$^{a}$ | 7.92 |
| ±SEM | 0.174 | 0.089 | 0.080 | 0.063 | 0.123 | 0.249 | 0.152 | 0.489 |
| P-value | < 0.0001 | < 0.0001 | 0.0002 | < 0.0001 | 0.578 | 0.050 | 0.014 | 0.931 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

**Table 6** Effect of magnetization and temperature of water on pH of some organic acids, exogenous enzymes, and mash or pelleted complete diets

| Effects | Ammonium formate | Sodium diacetate | Calcium propionate | Citric acid | Fumaric acid | Tartaric acid | Betamannanase (Hemicell®) | NSP degrading enzyme (Grindazym®) | Mash diet | Pelleted diet |
|---|---|---|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | | | | |
| Deionized | 5.64$^{b}$ | 4.59$^{b}$ | 7.51 | 2.04$^{b}$ | 2.03$^{b}$ | 2.03 | 6.10$^{b}$ | 5.12$^{b}$ | 7.50$^{b}$ | 7.75$^{b}$ |
| Magnetized | 6.26$^{a}$ | 4.73$^{a}$ | 7.66 | 2.16$^{a}$ | 2.12$^{a}$ | 2.03 | 6.45$^{a}$ | 5.54$^{a}$ | 8.15$^{a}$ | 8.31$^{a}$ |
| ±SEM | 0.016 | 0.023 | 0.055 | 0.020 | 0.021 | 0.017 | 0.095 | 0.065 | 0.078 | 0.066 |
| P-value | < 0.0001 | 0.0026 | 0.086 | 0.0014 | 0.020 | 0.907 | 0.026 | 0.0003 | 0.0004 | 0.0003 |
| **Temperature** | | | | | | | | | | |
| 21 °C | 6.22$^{a}$ | 4.66 | 7.70$^{a}$ | 2.28$^{a}$ | 2.32$^{a}$ | 2.20$^{a}$ | 6.16 | 5.94$^{a}$ | 7.90 | 8.08 |
| 41 °C | 5.68$^{b}$ | 4.66 | 7.46$^{b}$ | 1.93$^{b}$ | 1.83$^{b}$ | 1.85$^{b}$ | 6.39 | 5.72$^{b}$ | 7.75 | 7.98 |
| ±SEM | 0.016 | 0.023 | 0.055 | 0.020 | 0.021 | 0.017 | 0.089 | 0.065 | 0.078 | 0.066 |
| P-value | < 0.0001 | 0.832 | 0.011 | < 0.0001 | < 0.0001 | < 0.0001 | 0.108 | 0.046 | 0.212 | 0.325 |
| **Interactions** | | | | | | | | | | |
| Deionized 21 °C | 5.70$^{b}$ | 4.57 | 7.61 | 2.20$^{b}$ | 2.24$^{b}$ | 2.21 | 6.46$^{b}$ | 5.82$^{b}$ | 7.65$^{b}$ | 7.77$^{b}$ |
| Deionized 41 °C | 5.58$^{c}$ | 4.62 | 7.41 | 1.88$^{c}$ | 1.83$^{c}$ | 1.85 | 5.75$^{c}$ | 5.03$^{b}$ | 7.36$^{c}$ | 7.73$^{b}$ |
| Magnetized 21 °C | 6.74$^{a}$ | 4.75 | 7.80 | 2.35$^{a}$ | 2.41$^{a}$ | 2.20 | 5.86$^{c}$ | 6.42$^{a}$ | 8.16$^{a}$ | 8.39$^{a}$ |
| Magnetized 41 °C | 5.78$^{b}$ | 4.71 | 7.51 | 1.98$^{c}$ | 1.83$^{c}$ | 1.85 | 7.04$^{a}$ | 6.06$^{ab}$ | 8.14$^{a}$ | 8.23$^{a}$ |
| ±SEM | 0.022 | 0.033 | 0.078 | 0.028 | 0.030 | 0.025 | 0.134 | 0.092 | 0.110 | 0.093 |
| P-value | < 0.0001 | 0.211 | 0.552 | 0.041 | 0.020 | 0.907 | < 0.0001 | < 0.0001 | 0.049 | 0.047 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

In addition, it has been reported that magnetization improves the solubility of minerals in milk (Andersson and Knudsen, 1983). Thus, such phenomenon can affect the solubility of feedstuffs in water, and subsequently modify the pH of solution. Furthermore, anecdotal evidence shows that magnetic fields may change the physicochemical properties of water or prepared laboratory solutions (Morimitsu *et al.* 2000) by decreasing surface tension (Amiri and Dadkhah, 2006; Lino and Fujimura, 2009), pH value, nucleation and growth, and other chemical characteristics (Holysz *et al.* 2002; Eshaghi and Gholizadeh, 2004). As an example, Chang and Weng (2006) found that the number of hydrogen bonds increases slightly as the strength of the magnetic field is increased. Their study reveals that the structure of water is more stable and the ability of the water molecules to form hydrogen bonds is enhanced, when a magnetic field is applied. In addition, the behavior of the water molecules changes under the influence of a magnetic field. Key factors for the effectiveness of treatment are the type of equipment (magnetic or electric), water temperature as well as the quality and the mode of operation such as flow rate (Lin and Yotvat, 1990; Toledo *et al.* 2009), and impurities (Amiri and Dadkhah, 2006).

The pH of most feed ingredients, especially organic acids (citric, fumaric and tartaric acids) was found to be decreased in warm water (Table 6). In a weak acid or weak base, most of the acid or base is not ionized (broken into smaller components like $H^+$ and $OH^-$). The state of energy at high temperature helps these molecules to break apart. In the case of acids this produces more $H^+$. Subsequently, acids lower pH. On the other hand, Pang and Deng (2008), have reported that magnetization can be influenced by water temperature. In fact, by increasing water temperature from 35 to 95 ˚C, the, magnetization effect can be reduced.

Moreover, the freezing temperature below which the freezing of confined water occurs shifts to a higher value as the magnetic field enhances (Zhang *et al.* 2010). In this regard, Inaba *et al.* (2004) reported that melting temperature of magnetized water was higher than untreated water. All in all, the above mentioned studies show that there is a link between magnetization and water temperature.

The results of ABC for various groups of feed ingredients are shown in Tables 7 to 12. Energy sources (cereals and fats in Table 7) together with synthetic amino acids (Table 9), common salt (Table 10), and some additives such as prebiotic and zeolite (Table 11) had the lowest values of ABC (less than 400 mEq/kg). Protein sources (Tables 8 and 9), and some supplements (Table 10) and additives (Table 11), had an average ABC of about 400-1000 mEq/kg. Finally, some vitamins and minerals (Table 10), had higher levels of ABC (more than 1000 mEq/kg) among all tested ingredients. Calcium carbonate and sodium bicarbonate (Table 10), along with ammonium formate and calcium propionate (Table 12), had the highest ABC values among all ingredients. Meanwhile, organic acids category had the lowest pH and negative ABC values (Table 12).

The findings of the current study are consistent with the results of Lawlor *et al.* (2005), reporting higher ABC in minerals and energy sources such as cereal grains with lower ABC among various feedstuffs. All in all, initial pH and $ABC_3$ varied greatly between individual ingredients. Categories of ingredients were substantially different regarding initial pH and ABC. Acid salts and minerals were the categories that had the highest ABC values. Large variation occurred between different types of mineral. The influence of processing likes pelleting and extruding, on pH and ABC of the whole ration and two oilseeds can be seen in Table 13.

**Table 7** Effect of magnetization and temperature of water on the $ABC_3$ (mEq/kg) of cereal grains, their by-products, oil and fat

| Effects | Corn | Wheat | Barley | Wheat bran | Rice bran | Vegetable oil | Fat powder |
|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | |
| Deionized | 182 | 400 | 416$^b$ | 689$^b$ | 562$^b$ | 226 | 212$^b$ |
| Magnetized | 164 | 339 | 491$^a$ | 1363$^a$ | 697$^a$ | 370 | 311$^a$ |
| ±SEM | 5 | 32 | 9 | 33 | 13 | 52 | 14 |
| P-value | 0.050 | 0.204 | 0.0005 | < 0.0001 | < 0.0001 | 0.078 | 0.0016 |
| **Temperature** | | | | | | | |
| 21 ˚C | 175 | 481$^a$ | 525$^a$ | 1278$^a$ | 802$^a$ | 454$^a$ | 305$^a$ |
| 41 ˚C | 170 | 257$^b$ | 382$^b$ | 774$^b$ | 457$^b$ | 142$^b$ | 218$^b$ |
| ±SEM | 4 | 31 | 9 | 33 | 13 | 52 | 14 |
| P-value | 0.494 | 0.0007 | < 0.0001 | < 0.0001 | < 0.0001 | 0.001 | 0.003 |
| **Interactions** | | | | | | | |
| Deionized 21 ˚C | 191 | 589$^a$ | 549$^a$ | 747$^b$ | 718 | 364 | 197$^b$ |
| Deionized 41 ˚C | 171 | 210$^c$ | 284$^c$ | 630$^c$ | 406 | 88 | 209$^b$ |
| Magnetized 21 ˚C | 160 | 374$^b$ | 502$^{ab}$ | 1925$^a$ | 886 | 545 | 413$^a$ |
| Magnetized 41 ˚C | 170 | 304$^b$ | 480$^b$ | 800$^b$ | 508 | 196 | 228$^{ab}$ |
| ±SEM | 7 | 46 | 13 | 47 | 21 | 80 | 21 |
| P-value | 0.069 | 0.007 | < 0.0001 | < 0.0001 | 0.140 | 0.635 | 0.0006 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).
$ABC_3$: is acid-binding capacity of a feedstuff at titer point of 3 (pH=3).

**Table 8** Effect of magnetization and temperature of water on the $ABC_3$ (mEq/kg) of oilseeds and their by-products

| Effects | Full fat soybean | Extruded soybean | Soybean meal | Flaxseed | Extruded flaxseed | Cottonseed meal | Canola meal | Sunflower meal | Safflower meal |
|---|---|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | | | |
| Deionized | 757 | 622 | 707$^{b}$ | 346$^{b}$ | 481 | 323$^{b}$ | 574$^{b}$ | 618 | 458 |
| Magnetized | 846 | 724 | 933$^{a}$ | 899$^{a}$ | 472 | 486$^{a}$ | 839$^{a}$ | 716 | 433 |
| ±SEM | 49 | 58 | 23 | 29 | 8 | 9 | 21 | 43 | 15 |
| P-value | 0.201 | 0.253 | < 0.0001 | < 0.0001 | 0.514 | < 0.0001 | < 0.0001 | 0.148 | 0.263 |
| **Temperature** | | | | | | | | | |
| 21 ˚C | 786 | 627 | 869$^{a}$ | 807$^{a}$ | 519$^{a}$ | 409 | 989$^{a}$ | 732 | 515$^{a}$ |
| 41 ˚C | 813 | 719 | 771$^{b}$ | 438$^{b}$ | 435$^{b}$ | 399 | 400$^{b}$ | 602 | 376$^{b}$ |
| ±SEM | 49 | 58 | 23 | 29 | 9 | 9 | 21 | 44 | 15 |
| P-value | 0.698 | 0.299 | 0.016 | < 0.0001 | < 0.0001 | 0.462 | < 0.0001 | 0.066 | 0.0001 |
| **Interactions** | | | | | | | | | |
| Deionized 21 ˚C | 725 | 696$^{b}$ | 756$^{b}$ | 358$^{c}$ | 511$^{a}$ | 435$^{b}$ | 758$^{b}$ | 678 | 603$^{a}$ |
| Deionized 41 ˚C | 780 | 549$^{c}$ | 628$^{c}$ | 334$^{c}$ | 451$^{b}$ | 316$^{c}$ | 390$^{c}$ | 558 | 313$^{c}$ |
| Magnetized 21 ˚C | 846 | 559$^{c}$ | 989$^{a}$ | 987$^{a}$ | 526$^{a}$ | 588$^{a}$ | 996$^{a}$ | 786 | 426$^{b}$ |
| Magnetized 41 ˚C | 847 | 890$^{a}$ | 786$^{b}$ | 518$^{b}$ | 419$^{b}$ | 414$^{b}$ | 410$^{c}$ | 646 | 439$^{b}$ |
| ±SEM | 70 | 83 | 31 | 42 | 13 | 12 | 30 | 61 | 21 |
| P-value | 0.698 | 0.020 | < 0.0001 | 0.0003 | 0.048 | < 0.0001 | < 0.0001 | 0.874 | < 0.0001 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

$ABC_3$: is acid-binding capacity of a feedstuff at titer point of 3 (pH=3).

**Table 9** Effect of magnetization and temperature of water on the $ABC_3$ (mEq/kg) of some protein and amino acid sources

| Effects | Corn gluten meal | Fish meal | Meat meal | L-lysine HCl | L-threonine | DL-methionine |
|---|---|---|---|---|---|---|
| **Water** | | | | | | |
| Deionized | 680$^{b}$ | 596 | 394$^{b}$ | 264$^{b}$ | 185$^{b}$ | 273$^{b}$ |
| Magnetized | 837$^{a}$ | 576 | 481$^{a}$ | 481$^{a}$ | 787$^{a}$ | 728$^{a}$ |
| ±SEM | 28 | 67 | 9 | 8 | 18 | 41 |
| P-value | 0.004 | 0.833 | 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 |
| **Temperature** | | | | | | |
| 21 ˚C | 795 | 579 | 434 | 361 | 479 | 467 |
| 41 ˚C | 722 | 592 | 441 | 384 | 493 | 533 |
| ±SEM | 28 | 67 | 9 | 8 | 18 | 41 |
| P-value | 0.108 | 0.889 | 0.598 | 0.096 | 0.617 | 0.276 |
| **Interactions** | | | | | | |
| Deionized 21 ˚C | 799$^{ab}$ | 645 | 335$^{c}$ | 253$^{c}$ | 126$^{c}$ | 119$^{c}$ |
| Deionized 41 ˚C | 562$^{b}$ | 546 | 430$^{b}$ | 453$^{b}$ | 245$^{b}$ | 428$^{b}$ |
| Magnetized 21 ˚C | 883$^{a}$ | 513 | 533$^{a}$ | 577$^{a}$ | 833$^{a}$ | 816$^{a}$ |
| Magnetized 41 ˚C | 792$^{ab}$ | 638 | 452$^{b}$ | 316$^{c}$ | 741$^{a}$ | 639$^{a}$ |
| ±SEM | 40 | 82 | 12 | 12 | 26 | 52 |
| P-value | 0.003 | 0.256 | < 0.0001 | < 0.0001 | 0.0028 | 0.002 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

$ABC_3$: is acid-binding capacity of a feedstuff at titer point of 3 (pH=3).

**Table 10** Effect of magnetization and temperature of water on the $ABC_3$ (mEq/kg) of some vitamin and mineral sources

| Effects | Vitamin premix | Choline chloride | Vitamin $D_3$ | Vitamin E + Se | Mineral premix | NaCl | Sodium bicarbonate | Calcium carbonate | Oyster shell | Dicalcium phosphate | Monocalcium phosphate |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | | | | | |
| Deionized | 1332$^{b}$ | 305$^{b}$ | 1296 | 1427$^{b}$ | 1082$^{b}$ | 137$^{b}$ | 12133 | 8933$^{b}$ | 3876$^{b}$ | 1124$^{b}$ | 665$^{b}$ |
| Magnetized | 2329$^{a}$ | 343$^{a}$ | 1196 | 2019$^{a}$ | 1802$^{a}$ | 165$^{a}$ | 12433 | 10733$^{a}$ | 4806$^{a}$ | 1513$^{a}$ | 1111$^{a}$ |
| ±SEM | 87 | 11 | 49 | 35 | 88 | 7 | 129 | 276 | 91 | 33 | 35 |
| P-value | < 0.0001 | 0.032 | 0.190 | 0.0002 | 0.0002 | 0.028 | 0.139 | 0.001 | < 0.0001 | < 0.0001 | < 0.0001 |
| **Temperature** | | | | | | | | | | | |
| 21 ˚C | 2697$^{a}$ | 333 | 1465$^{a}$ | 2353$^{a}$ | 1489 | 201$^{a}$ | 12666$^{a}$ | 10933$^{a}$ | 5376$^{a}$ | 1841$^{a}$ | 1200$^{a}$ |
| 41 ˚C | 964$^{b}$ | 315 | 1028$^{b}$ | 1093$^{b}$ | 1395 | 101$^{b}$ | 11900$^{b}$ | 8733$^{b}$ | 3306$^{b}$ | 769$^{b}$ | 576$^{b}$ |
| ±SEM | 87 | 11 | 49 | 65 | 94 | 8 | 129 | 276 | 91 | 34 | 35 |
| P-value | < 0.0001 | 0.285 | 0.0002 | < 0.0001 | 0.471 | < 0.0001 | 0.003 | 0.0003 | < 0.0001 | < 0.0001 | < 0.0001 |
| **Interactions** | | | | | | | | | | | |
| Deionized 21 ˚C | 1836$^{b}$ | 333$^{a}$ | 1630$^{a}$ | 1740$^{b}$ | 1467$^{b}$ | 181$^{b}$ | 12533$^{a}$ | 12000$^{a}$ | 3886$^{b}$ | 1037$^{b}$ | 557$^{bc}$ |
| Deionized 41 ˚C | 828$^{c}$ | 276$^{b}$ | 962$^{c}$ | 1072$^{c}$ | 698$^{c}$ | 93$^{c}$ | 11733$^{b}$ | 5866$^{c}$ | 2746$^{c}$ | 481$^{c}$ | 380$^{c}$ |
| Magnetized 21 ˚C | 3558$^{a}$ | 333$^{a}$ | 1300$^{b}$ | 2966$^{a}$ | 1511$^{b}$ | 221$^{a}$ | 12800$^{a}$ | 11600$^{a}$ | 6866$^{a}$ | 2645$^{a}$ | 1843$^{a}$ |
| Magnetized 41 ˚C | 1101$^{b}$ | 354$^{a}$ | 1093$^{c}$ | 1113$^{c}$ | 2093$^{a}$ | 108$^{c}$ | 12066$^{b}$ | 9866$^{b}$ | 3866$^{b}$ | 1212$^{b}$ | 773$^{b}$ |
| ±SEM | 123 | 15 | 69 | 92 | 115 | 11 | 181 | 391 | 129 | 49 | 50 |
| P-value | 0.0002 | 0.031 | 0.010 | 0.0001 | 0.0003 | 0.037 | 0.045 | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

$ABC_3$: is acid-binding capacity of a feedstuff at titer point of 3 (pH=3).

**Table 11** Effect of magnetization and temperature of water on the $ABC_3$ (mEq/kg) of some additives

| Effects | Bentonite | Zeolite | Whey powder | Yeast (*Saccharomyces cerevisiae*) | Prebiotic (Fermacto®) | Diclazuril | Maduramycin | Salinomycin |
|---|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | | |
| Deionized | 351 | 277 | 656[b] | 723 | 192 | 320 | 336[b] | 433[b] |
| Magnetized | 497 | 289 | 826[a] | 716 | 173 | 364 | 436[a] | 543[a] |
| ±SEM | 52 | 8 | 9 | 12 | 15 | 19 | 10 | 17 |
| P-value | 0.086 | 0.318 | < 0.0001 | 0.703 | 0.419 | 0.147 | 0.0001 | 0.002 |
| **Temperature** | | | | | | | | |
| 21 °C | 568[a] | 317[a] | 810[a] | 745[a] | 267[a] | 378[a] | 374 | 465 |
| 41 °C | 280[b] | 249[b] | 671[b] | 694[b] | 98[b] | 306[b] | 398 | 511 |
| ±SEM | 52 | 8 | 9 | 12 | 15 | 19 | 10 | 17 |
| P-value | 0.004 | 0.0004 | < 0.0001 | 0.020 | < 0.0001 | 0.028 | 0.124 | 0.095 |
| **Interactions** | | | | | | | | |
| Deionized 21 °C | 476[b] | 340[a] | 752[b] | 804[a] | 324[a] | 330[b] | 320[b] | 492[ab] |
| Deionized 41 °C | 226[c] | 214[c] | 560[c] | 642[c] | 79[c] | 310[b] | 352[b] | 429[b] |
| Magnetized 21 °C | 660[a] | 294[b] | 869[a] | 686[bc] | 210[b] | 446[a] | 428[a] | 437[b] |
| Magnetized 41 °C | 333[b] | 284[b] | 783[b] | 746[b] | 136[bc] | 282[b] | 444[a] | 593[a] |
| ±SEM | 74 | 11 | 13 | 17 | 21 | 27 | 14 | 24 |
| P-value | 0.046 | 0.0012 | 0.005 | 0.0002 | 0.002 | 0.009 | 0.045 | 0.049 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).
$ABC_3$: is acid-binding capacity of a feedstuff at titer point of 3 (pH=3).

**Table 12** Effect of magnetization and temperature of water on the $ABC_3$ (mEq/kg) of some organic acids, exogenous enzymes, and mash or pelleted complete diets

| Effects | Ammonium formate | Sodium diacetate | Calcium propionate | Citric acid | Fumaric acid | Tartaric acid | Betamannanase (Hemicell®) | NSP degrading enzyme ( Grindazym®) | Mash diet | Pelleted diet |
|---|---|---|---|---|---|---|---|---|---|---|
| **Water** | | | | | | | | | | |
| Deionized | 12385[b] | 7325[b] | 11025[b] | -4075 | -5370 | -5477 | 295[b] | 371[b] | 839 | 819 |
| Magnetized | 13942[a] | 8033[a] | 12100[a] | -3829 | -5309 | -5500 | 340[a] | 818[a] | 777 | 888 |
| ±SEM | 126 | 84 | 130 | 132 | 130 | 102 | 12 | 33 | 18 | 25 |
| P-value | < 0.0001 | 0.0004 | 0.0004 | 0.209 | 0.739 | 0.875 | 0.028 | < 0.0001 | 0.054 | 0.095 |
| **Temperature** | | | | | | | | | | |
| 21 °C | 13285 | 7542 | 11458 | -3654[a] | -4079[a] | -5044[a] | 352[a] | 895[a] | 833 | 925[a] |
| 41 °C | 13042 | 7816 | 11666 | -4250[b] | -6600[b] | -5933[b] | 283[b] | 295[b] | 782 | 782[b] |
| ±SEM | 126 | 84 | 130 | 132 | 130 | 102 | 5.62 | 32 | 18 | 25 |
| P-value | 0.211 | 0.051 | 0.291 | 0.009 | < 0.0001 | 0.0001 | 0.003 | < 0.0001 | 0.087 | 0.004 |
| **Interactions** | | | | | | | | | | |
| Deionized 21 °C | 11703[c] | 6851[b] | 10516[c] | -3850 | -4407[a] | -5021[a] | 394[a] | 483[b] | 893 | 860 |
| Deionized 41 °C | 13066[b] | 7800[a] | 11533[b] | -4300 | -6333[b] | -5933[b] | 196[c] | 260[b] | 785 | 778 |
| Magnetized 21 °C | 14866[a] | 8233[a] | 12400[a] | -3458 | -3751[a] | -5066[a] | 310[b] | 997[a] | 774 | 990 |
| Magnetized 41 °C | 13018[b] | 7833[a] | 11800[ab] | -4200 | -6866[b] | -5933[b] | 370[ab] | 330[b] | 780 | 786 |
| ±SEM | 178 | 119 | 184 | 187 | 160 | 144 | 17 | 45 | 26 | 36 |
| P-value | < 0.0001 | 0.0005 | 0.0024 | 0.443 | 0.008 | 0.047 | < 0.0001 | < 0.0001 | 0.061 | 0.133 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).
$ABC_3$: is acid-binding capacity of a feedstuff at titer point of 3 (pH=3).

**Table 13** Effect of pelleting and extrusion on pH and $ABC_3$ of feeds

| Type of processing | pH | $ABC_3$ |
|---|---|---|
| **Pelleting of complete diet** | | |
| Mash diet | 7.65 | 893 |
| Pelleted diet | 7.77 | 860 |
| SEM | 0.041 | 40 |
| P-value | 0.111 | 0.589 |
| **Extruding of soybean** | | |
| Full fat soybean | 5.93[b] | 725 |
| Extruded soybean | 7.23[a] | 696 |
| SEM | 0.047 | 93 |
| P-value | < 0.0001 | 0.820 |
| **Extruding of flaxseed** | | |
| Full fat flaxseed | 6.92[a] | 358[b] |
| Extruded flaxseed | 5.75[b] | 511[a] |
| SEM | 0.022 | 11 |
| P-value | < 0.0001 | 0.0002 |

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

Pelleting did not have any pronounced impact on pH or ABC of whole broiler chickens' growth diet. Extruding full fat oilseeds by heat and pressure did not alter ABC of soybean, but significantly increased ABC of flaxseed. Interestingly, pH of extruded soybean was significantly increased, but pH of extruded flaxseed was significantly decreased as compared with unprocessed oilseeds.

## CONCLUSION

The results of this study show that feed ingredient, type of processing, solution for ABC evaluation and ambient temperature, are determining factors for ABC of feedstuffs. Some issues derived from the above findings may have a direct link to the secretions, digestion, and absorption processes occurring in the gastrointestinal tract of birds, within an aqueous solution at about 41 ˚C. As previously noted, these parameters may have a pronounced influence on output such as pH and ABC. Obviously, pH has a well known effect on the absorption of some nutrients such as calcium in the intestine. Therefore, it might be useful to include these criteria into practical poultry feeding.

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