Binding Efficacy of Clay Binders in Optimized Ash-Based Vitamin-Mineral Block Licks for Cattle

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Abstract

An experiment was done to fabricate summer and winter optimized ash-based vitamin-mineral block lick specimens using cement, bentonite, kaolinite and a combination of these as binders in a ratio of 1:1(w/w) at 15% and 20% inclusion levels, respectively. Treatments were: cement, bentonite, kaolinite, bentonite + cement, bentonite + kaolinite and cement + kaolinite. Bentonite, kaolinite and ash (prime ingredient) were analyzed for mineral profile prior to fabrication. Resulting block specimens were analyzed for compressive strength and water absorption as a measure of the binding efficacy. There was no significant difference ($P>0.001$) in compressive strength ($525 \pm 11.43 \text{ kPa}$) for cement and bentonite + cement summer blocks. Compressive strength was significantly higher ($P<0.001$) in winter block specimens made from the combination of cement and bentonite ($47.33 \pm 1.37 \text{ kPa}$). Clays as sole binder could not agglutinate winter blocks. Summer block specimens comprising of cement had the significantly least ($P<0.001$) water absorption value ($1.40 \pm 0.923\%$). Therefore, cement can be combined with bentonitic clay at a ratio of 1:1 summer block licks (500 kPa) and winter block licks ($39 \pm 1.37 \text{ kPa}$) of desirable strength that animals can lick slowly.

1.0 Introduction

Kumaresan et al. (2010), concluded that cattle reared under smallholder farms lack most minerals and supplementation is required for optimal production. Smallholder livestock farmers are facing a challenge on what and how to supplement livestock to improve production levels (Gusha et al., 2017). Gusha et al. (2017), further emphasizes the need for locally available supplements that are of high quality, affordable to resource constrained farmers and accommodate the most critical periods of quality feed deficit.

Solid feed blocks to supplement low quality feed resources has been an exceptionally successful tool for improved ruminant feeding in many countries (Getu-Kitaw et al., 2011). Usage of solid feed blocks to offer nitrogen, vitamins and minerals deficient in fibrous feeds makes transportation, storage and feeding easier. Toxicity risks are reduced when compared to practices such like sprinkling urea solution on fodder, urea-treatment of crop residues and addition of minute quantities of urea in drinking water (Dove, 2009).

“Cold chain process” which does not involve the use of heat energy but binding agents in the manufacture of blocks is the commonly used method. Binders agglutinate the ingredients to form a malleable and mouldable mixture that paste attains solidity and becomes resistant when hard-pressed and dried (Furtado et al., 2018). Vitamin and mineral block supplements available on the Zimbabwean market are commonly imported. Resource constrained farmers face an impediment in accessing the imported multi-mineral blocks for their animals.

Preliminary work done at Chinhoyi University of Technology, Zimbabwe in 2017 to fabricate locally based ash-based vitamin-mineral block supplement through the “cold chain process”, using cement as a binding agent showed the binder used has to be acceptable to the communal farmers. Though building cement is used in block lick production, baseline surveys showed that farmers had ethical concerns on the

scarceness of observed intake of cement by livestock animals as well as probable deposition of heavy metals in animal tissues (Asaolu, 2012). Farmers also raised concerns on the possibility of cement to harden the block, hence limiting the release and utilization of nutrients. Kikelomo (2016) highlighted negative health effects and high cost associated with the use of building cement in the production of feed block supplements. Therefore, alternative binders are necessary since vitamin-mineral block licks are viable supplements that improve utilization of low quality pastures, hence animal performance.

Clays are also alternative binders that can be used in manufacturing feed supplement blocks. Geophagy (the practise of eating soil, especially clay) has been observed in humans and animals. Voluntary intake of clays such as bentonite has been documented in humans and animals (Krishnamani & Mahaney, 2000; Wilson, 2003). In communal areas of Zimbabwe, voluntary ingestion of termite mounds may be observed. Addition of clays to diets can help bind toxins in the animals' (Subramaniam & Kim, 2015). Omonoyi et al. (2013) incorporated cement and mixture clay as binder in the manufacture of urea-molasses multi-nutrient block. Binder type and concentration used in the fabrication of feed block supplements influences its hardness and compactness as well as the release of nutrients to the animal.

Therefore, this study was conducted to fabricate summer and winter optimized ash-based vitamin-mineral block lick specimens using cement, bentonite, and kaolinite binders and comparatively determine their binding efficacy. Prior to fabrication, selected ingredients were analyzed for mineral profile. It was hypothesized that clay-based binders can produce block licks of the same properties as those agglutinated by cement.

2.0 Materials And Methods

2.1 Ingredients

Ash was collected from curing barn stoves at Chinhoyi University of Technology Farm, sifted through a 1mm sieve to get rid of all coarse material. Samples were randomly collected from the curing barn batches of ash and were thoroughly mixed to form composite samples that were analyzed for mineral profile. Ordinary building cement was purchased from certified local commercial suppliers. The composition was 80% clinker + 17% additive + 3% gypsum as indicated by the manufacturer. Bentonitic and kaolinitic clays were acquired in ground form from certified suppliers in Gweru. Samples were randomly collected from and were analyzed for mineral profiles.

2.2 Determination of mineral profiles

Determination of mineral profiles was carried out at Agrianalysis Centre (AgLabs), Harare, Zimbabwe. Samples of ash, bentonite and kaolinite were analyzed for extractable minerals using different solvent methods for Flame Atomic Absorption Spectroscopy. Methods of sample preparation and analyses were adopted from Elmer (1996). Basically, ground samples were weighed and placed in a volumetric flask with the addition of an extracting solution (double acid). The extract was then concentrated and analyzed

for Ca, Mg, K, Na, Fe, I, Zn, Se and Cu. Phosphorus was determined colorimetrically using UV –Vis Spectrophotometer (Lasany IDO-4S).

2.3 Fabrication of specimens

Block specimens measuring 100 mm in cuboid form were made using the “cold chain process” of block lick production (Sansoucy, 1986 as cited in Sansoucy et al., 1988). Ground base ingredients excluding the binders were weighed and mixed thoroughly using shovels. Separately, the binder was mixed with known volumes of distilled water and stirred thoroughly to form a homogeneous malleable paste which was thereafter mixed with the well-blended dry ingredients using shovels. The homogenous moldable mixture was manually compacted into molds and air-dried. Formulations were made with six binder compositions at recommended optimal inclusion levels of 15% and 20% by weight as shown in Table 1. Specimens were made for both summer and winter blocks with 15 replicates per treatment.

Table 1
Binders and respective proportions used for fabricating experimental block specimens

Binder	Summer block (Binder inclusion %)	Winter block (Binder inclusion %)
Bentonite	15	20
Cement	15	20
Kaolinite	15	20
Bentonite + Cement	7.5 + 7.5	10 + 10
Bentonite + Kaolinite	7.5 + 7.5	10 + 10
Cement + Kaolinite	7.5 + 7.5	10 + 10

2.4 Experimental design

The experimental design was a completely randomized design (CRD) composed of 6 binder compositions as treatments and 100mm cuboid block lick specimens as experimental units. Treatments were as shown in Table 1. Each treatments had 15 replicates. Variables being measured to determine block lick quality were compressive strength and water absorption.

2.5 Determination of compressive strength

Compressive strength tests were carried out in a completely randomized (CRD) design at Standards Association of Zimbabwe (SAZ) Coventry Laboratories. Specimens were analyzed for compressive strength after 7 days of air drying using a universal forcing machine as per IS 5816 – 1999 as cited in (Garad, 2019).

The compressive strength was calculated by using the Eq. 1 (Garad, 2019).

$$F = P/A. \text{ Eq. 1}$$

Where: F = Compressive strength of the specimen (kPa).

P = Maximum load applied to the specimen (N).

A = Cross sectional area of the specimen (mm²)

2.6 Water absorption tests

Water absorption tests were performed at Chinhoyi University of Technology, Animal Production and Technology Laboratory after 10 days of drying by initially weighing the block specimens, soaking them in distilled water for 24 hours then weighing again the specimens after removing from water and wiping using a damp cloth. Water absorption values were obtained from the formula given below, based on NBR 9778 as cited in (Furtado et al., 2018). Water absorption tests were carried out in a completely randomized design.

$$[(A - B)/B] \times 100\%. \text{ Eq. 2}$$

Where:

A = weight of saturated specimen after immersion in water (kg)

B = initial weight of sample before immersion (kg)

2.7 Statistical Analysis

Data on mineral profiles, compressive strength and water absorption were analyzed in GenStat Discovery 4. Analysis of variance (ANOVA) in a completely randomized design (CRD) was used to analyze variance across treatments with binder type as the fixed effect and block specimen within a binder type as the random effect. Means were separated using the least significance difference test (LSD). The model used was: $Y_{ij} = \mu + T_i + E_{ij}$

Where: Y_{ij} = **Response variable** (compressive strength, water absorption),

μ = overall mean common to all observations,

T_i = effect of binder type,

E_{ij} = random error.

3.0 Results

Mineral profiles for ash (prime ingredient), bentonitic and kaolinitc clays are shown in Table 2. Bentonite and kaolinite have significant mineral contributions that are useful in nutritional status of feed block.

Bentonite proved to have high iron content. Ash as the prime ingredient has a beneficial mineral profile with high calcium content as shown in Table 2 below.

Table 2
Mineral profiles for ash, bentonite and kaolinite

	Ash	Kaolinitic clay	Bentonitic clay
Ca (%)	23.16 ± 0.68 ^c	1.57 ± 0.03 ^b	0.89 ± 0.02 ^a
P (%)	0.86 ± 0.30 ^a	ND	ND
K (%)	13.51 ± 0.34 ^c	0.27 ± 0.03 ^a	7.32 ± 0.32 ^b
Mg (%)	0.24 ± 0.03 ^a	1.19 ± 0.02 ^c	0.49 ± 0.02 ^b
Fe (%)	1.37 ± 0.01 ^a	3.10 ± 0.10 ^b	7.40 ± 0.10 ^c
Cu (mg/kg)	20.61 ± 0.56 ^b	15.48 ± 0.50 ^a	25.50 ± 0.50 ^c
Co (mg/kg)	ND	11.60 ± 0.60 ^a	31.50 ± 0.50 ^b
Zn(mg/kg)	110.05 ± 6.23 ^b	138.25 ± 0.75 ^c	91.25 ± 1.30 ^a
<i>abc Means in a row figures with different superscript differ significantly (P<0.001)</i>			

ND- Not detectable

3.1 Vitamin-Mineral Block specimens

An illustration of the summer block specimens is given in Fig. 1(a). Winter block specimens from clay binders deformed upon removal from the molds as shown from the blocks in the top left corner of Fig. 1(b). Winter specimens comprising of cement and a combination of cement and bentonite at 20% inclusion level were obtained in a well formed state. Bentonite and kaolinitic clays did not successfully bind winter block specimens.

3.2 Compressive strength for summer block specimens

The mean compressive strength (kPa) for varying binding agents is shown in Table 3. Cement alone produced summer block specimens with the highest values for compressive strength. The combination of cement and bentonite clay in a ratio of 1:1 (w/w) also produced blocks that were not significantly different in compressive strength from those of cement alone ($P < 0.001$). Compressive strength values decreased with the presence of kaolinite. Kaolinite alone produced summer blocks with the lowest ($P < 0.001$) compressive strength (250.0 ± 11.43 kPa).

Table 3
Effect of binder on mean compressive strength (kPa) for summer and winter block specimens

Binder	Summer blocks	Winter blocks
Cement	538.30 ± 11.43 ^d	31.33 ± 1.37 ^a
Bentonite	446.76 ± 11.43 ^c	ND
Kaolinite	250.0 ± 11.43 ^a	ND
Bentonite + Cement	513.13 ± 11.43 ^d	47.33 ± 1.37 ^b
Bentonite + Kaolinite	296.70 ± 11.43 ^b	ND
Cement + Kolinite	300.0 ± 11.43 ^b	ND
<i>abcd Means in a column with different superscripts differ significantly ($P \leq 0.001$)</i>		

ND- Not Determinable (samples deformed, resembling poor binding)

3.3 Compressive strength for winter block specimens

Winter block specimens made from cement alone and cement + bentonite at 20% inclusion level were tested for compressive strength. A binder inclusion level of 15% could not efficiently agglutinate the winter block specimens. Bentonite, kaolinite, bentonite + kaolinite and cement + kaolinite could not successfully agglutinate winter block materials. Means for compressive strength were significantly higher ($P < 0.001$) in winter block specimens made from cement + bentonite than specimens made from cement alone (Table 3).

3.4 Water absorption for summer block specimens

Block specimens comprising of cement + bentonite binder had a significantly higher ($P < 0.001$) water absorption value ($9.57 \pm 0.92\%$) than cement specimens (Table 4). Summer block specimens agglutinated solely by clay-based binders absorbed relatively large amounts of water to the extent of deforming the block. Resultantly, water absorption values were not determinable.

Table 4
Effect of binder on mean water absorption (%) for summer and winter block lick specimens

Binder	Summer blocks	Winter blocks
Cement	1.40 ± 0.92 ^a	25.87 ± 0.59 ^a
Bentonite	ND	ND
Kaolinite	ND	ND
Bentonite + Cement	9.57 ± 0.92 ^b	28.77 ± 0.59 ^b
Bentonite + Kaolinite	ND	ND
Cement + Kolinite	ND	ND
<i>^{ab}Means in a column with different superscript differ significantly (P<0.001)</i>		

ND-Not Determinable (samples deformed in water, resembling poor binding)

3.5 Water absorption for winter block specimens

Winter block specimens made from bentonite + cement absorbed more water when compared to specimens made from cement alone (Table 4).

4.0 Discussion

Bentonite and kaolinite, apart from being binders, may contribute to the mineral profile of the produced block licks. Bagherzadeh (2020), encourages the use of a binding agent that includes mineral components. Bentonite and kaolinite could provide nutritional benefit to animals because of the mineral components present in them. Iron, magnesium, copper, cobalt, manganese and zinc are other minerals vital for cattle production that can be supplied from block ingredients including binders. Feed grade ash has abundant calcium which can also be of nutritional benefit to livestock (Ndlovu, 2007).

The high values of compressive strength in cement could be as a result of the abundant presence of calcium hydroxide which chemically reacts with siliceous materials in the presence of water to form cementitious composites (Tierrer & Guillot, 2019). When mixed with water, the binding action of cement is enhanced. Cement becomes structural and load bearing once it sets. Strength of animal feed blocks is affected by the nature of gelling agent used (Sansoucy et al., 1988). Bentonite contains more silicon in its structure compared to kaolinite. Increased silicon from bentonite + cement produces a malleable mix with high binding capacity (Bekhiti et al., 2019). The increased silicon content could have resulted in the greater compressive strength values observed in blocks bound with a combination of cement and clay. Compressive strength relates to block quality in terms of hardness and handling. A block lick with a greater strength is relatively more stable than the one with a lower strength. Transportation, handling and administration is made easier with stable block licks. The latter block may disintegrate, thus making

handling and feeding difficult. Block licks that are crumbled due to poor strength block give room for animals to take bites instead of licking. Taking bites may lead to excess availability of some minerals to the animal, thus presenting toxicity risks or interferences. For instance, excess sulfur can interfere with copper metabolism, causing copper deficiency (Żarczyńska et al., 2017). Furtado et al. (2018), obtained greatest resistance to simple compression of 208.53 kPa with the addition of lime in multi-nutrient blocks.

The inclusion of clay binders in the block specimens resulted in increased water absorption value. Natural clays may absorb or lose water in response to changes in humidity conditions of the surrounding environment (Uddin, 2008). Bentonitic clays have variable interlayer space and can absorb relatively large quantities of water than kaolinite clays (Nadziakiewicza et al., 2019). Rull et al. (2015), also confirmed the excellent swelling behaviour of bentonite clay. Bentonites, mainly the montmorillonite clay type have high surface area and charge that make them capable of binding mineral nutrients (Rull et al., 2015). In contrast, kaolinites have 1:1 platelets held strongly by hydrogen bonds. Consequently, they have a fixed interlayer space, low cation exchange capacity and lower mineral element binding capacity when compared to bentonites (Avérous & Pollet, 2012). Durability and water-proof properties of lick blocks made from clay as sole binders are reduced and licks are vulnerable to bites (Furtado et al., 2018). The release of nutrients becomes quite rapid, resulting in high expenses and toxicity risk. The deformation of summer block specimens made from clays as sole binders upon water absorption tests could be attributed to high liquid limit of clays (Bekhiti et al., 2019). Sansoucy et al. (1988), highlighted that the “cold chain process” of feed block production is associated with a somewhat hygroscopic end-product. The method of block production used in the present study could also have contributed to the water absorption of the block specimens.

Base ingredients in winter block specimens such as cotton seed cake could not bind with clays. Natural adhesion of particles and mechanical load which forces inter-particle load enables binding mechanism (Tabil et al., 1997). When areas of contact increase during compression of solid particles, high binding forces are attained. An increase in particle size or inter-particle distance reduces the attraction between the particles (Fayed & Otten, 1997). Poor binding observed in winter block specimens in the current study could be attributed to increased inter-particle distance in protein and energy sources present in the blocks. The effectiveness of natural adhesion between ingredients' particles as well as the compaction done in the manufacture of winter block specimens was reduced. This could aid to explain the low compressive strength values for winter block specimens. Similarly, Santhiralingam & Sinniah (2018) observed poor compression when binding concentrates and roughages. Hygroscopic properties of protein and energy sources in winter blocks may have aided water absorption winter block specimens. Water absorption relates to the quality of the block, a higher water absorption value indicates a quick release of nutrients and vulnerability to bites by the animals (Furtado et al., 2018).

5.0 Conclusion

Our study has shown that bentonite + cement can be used successfully as a binding agent in the fabrication of both summer and winter ash-based vitamin- mineral block licks. This combined binder reduces the amount of cement used in cattle licks minimizes the ethical concern of its addition in cattle feeds. It also lessens the risk associated with heavy metal deposition in animal tissues. Though specific standards regarding strength and water absorption properties of cattle block licks are scarce, blocks made from cement alone, can be produced, handled and administered to animals without problems.

Declarations

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Ethics approval

The research was approved by Chinhoyi University of Technology Research and Ethics Committee.

Statement of animal rights

Not applicable.

Conflict of interest

The authors declare no known conflict of interest in regard to this manuscript.

Author contribution

JM, IDTM and CB conceived the research. RM conducted the research and wrote the manuscript. All authors read and approved the manuscript.

Consent for publication

Authors have approved the manuscript for publication.

Availability of data and material

Research data is available upon request.

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Figures

Figure 1

(a): Summer block specimens (b): Winter block specimens