CONSISTENT RELATIONSHIP OF BOTH WATER CONTENT AND ACTIVITY WITH MAIZE SEED QUALITY INDICES

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ABSTRACT

Seed quality can be explained using a range of indices that are acceptable within the standards set by the International Seed Testing Association. There is a need to improve existing models to explain the well-known variations in seed quality within and between crop species. The objective of this study was to determine the consistency of using grain water occurrence to explain seed quality in terms of viability and vigour in maize (Zea mays L.). Four sites were used over two seasons to grow three cultivars in order to monitor changes in water content, water activity, dry mass and total starch observed in different cob sections (tip, medium and bottom) at 30, 60 and 90 days after pollination. Seed quality was determined based on the germination and vigour of physiologically mature kernels. It is concluded that grains that seed quality is linked to the water activity and position on the cob.

KEYWORDS

maize, seed quality, vigour index, cob position, water activity

1. INTRODUCTION

1.1. Importance of Maize Seed Quality

Seed quality is the most basic measure of how a crop is expected to perform [1]. For most plant species it can be viewed as an expression of genetic value, which must be uniform. Environmental conditions have a significant effect on seed performance. That is why the current models to predict seedlot performance rely greatly on environmental variables in addition to genotype[2]. That is partly because it is not easy to control and retain some of the factors affecting seed quality. For example, grain yield is directly influenced by the photosynthetic ability of a crop, which in turn can be linked to the choices a farmer makes with respect to the season, site, and management. Despite the wide range of factors which can be controlled, it is important to continue to determine the physiological basis of seed quality in relation to components that are associated with both environment and genotype. Changes in seed chemistry are associated with grain water content at each phase of seed development. The quality and type of protein and starch determine whether or not a seed will be viable and vigorous. While physiological maturity is assumed for seeds, it is also well known that for most crops seeds of the same fruit do not reach physiological maturity at the same time[3]. Pollination does not occur at the same time for all seeds [26, 27]. Hence, physiological development will vary. Maize is one of the crop species characterised by having kernels positioned in rows that are not pollinated at the same time. The middle portion of a maize cob is fertilised earlier than the bottom and top sections. However, the distinction of kernels with respect to timing of pollination is not easy to perform with accuracy.

There are many opportunities to explain the variation in maize seed quality with respect to physiological, chemical and physical characteristics. This information is required to boost the characterisation of maize cultivars and hybrids based on genetics. It will serve to explain the genotype x environment interactions. Over decades, the seed science and technology research has provided consistently valid data to confirm that germination and vigour are important seed quality indices for cereal crops (including maize), oil grains and many vegetables [14, 15, 16, 17, 18]. The relationship between germination and biochemical activities that occur pre- and post-physiological maturity also explains the role of water content, because many oxidative and reductive processes are influenced by water [16, 20, 19, 22]. The performance of maize seed has also been linked to crop performance under field conditions, including response to environmental conditions and harvestable product from different perspectives [21].

1.2. Study Objective and Justification

This study focuses on grain water as seeks to propose its value as a quick indicator of maize seed quality. Seed viability from the early stages of development to physiological maturity is linked to grain water content in relation to grain water activity. The hypothesis of the study is that over a wide range of seed development phases after pollination, there is a consistent relationship between grain water content/activity and some of the well-studied seed quality indices that may be linked to seed performance and even final yield. This approach is innovative, but it is not without limitations as explained in the discussion of the results.

2. METHODOLOGY

2.1. Study Site and Plant Material

The existing production sites of the Baynsefield Estate(29°45'54.4392″S | 30°20'29.358″E) were used to randomly locate four sites of $400m^{-2}$ in size with fields that were used to cultivate three maize hybrids 200 m to 500m apart. The three selected hybrids were PAN 4R-528, DKC73-70 and P2319. Fertiliser application for growing maize was done according to soil analysis recommendations for dryland farming[4]. The average rainfall during the 2021/2022 growing season was 910mm.

2.2. Seed Sampling

Harvest periods were 30, 60 and 90 days after pollination (DAP), respectively. Each time three replications of ten cobs were harvested randomly from plants located inside of at least three rows from the outer row in each block. The cob length was deliberately selected to be 17±1.5 cm for all sites (blocks), cultivars and days after pollination. Each cob was divided into three equal sections based on position (tip, middle and bottom). To avoid damage, the kernels (seeds) located on the separating rows were excluded from the samples.

2.3. Seed Testing

2.3.1. Seed Physiological Characteristics

At each harvest stage, 1000 seeds per replication were used for germination (25 seeds per replication), seed water content and seed dry weight, following fresh mass determination and drying a sample of 100 seeds at 70° C for 72 hours according to the International Seed Testing Association (ISTA)[5].Water activity was determined using AQUALAN 4TE water activity metre[6,9] to Singh and Talukdar [9]. Total starch was determined in whole grains according to the previously published method[1].

2.3.2. Seed Quality

Seed quality was determined on the basis of germination test[5]and results were further used to determine vigour index in order to derive yield potential as previously published[7]fourteen days after sowing seeds in seedling trays and allowing them to grow under controlled environment conditions[8]. Only seeds derived from 90 days after pollination were used for seed quality test.

2.4. Statistical Analysis

The experiment was designed a randomised complete block with four sites used as blocks, three replications, three maize cultivars and three kernel positions on the cob. Data was analysed using analysis of variance (ANOVA) using GenStat 19th Edition Statistical Package VSN International, Hemel Hempstead, UK. Means were separated using Fisher's least significant difference (LSD) at 5% level of significance ($p \leq 0.05$).

3. Results and Discussion

This study demonstrated the consistent similarity of occurrence of seed water content and water activity during maize seed development (Figure 1). The relationship between these parameters and those that indicate grain mass accumulation was observed (Figure 2). Water content and water activity are related, but they need to be understood in the correct perspective. In food science research it is easy to separate these two as components of materials and the information is used for specific bioscience engineering purposes. Hence moisture (water) content is associated with the quantity of water in the tissues whereas water activity is associated with the difficulty to remove water from the tissues. The differentiation or similarity of water content and water activity is critically important in seed science, but it has not been adequately explored in my view. The results shown in Figure 1 show a simple correlation that is expected, but the meaning needs to be expanded in terms of biochemistry and physiology. However, this level of explanation allows us to make a strong argument that the influence of water content in maize grain is directly associated with the movement of water as such [note the correlation coefficients for grain water content (GWA) and grain water activity (GWA)] in Figure 1. The role of water in plant tissue has many biochemical and physiological dimensions and their interactions. The commonly studied ones include absorption, purely as a chemical reaction; a binding hydrate for formation of compounds, their structure and molecular diffusion; surface energy and capillary condensation which allows solution to form; and most commonly, the simple surface of water in plant material. To make the argument for careful interpretation of the relationship between water content and water activity for validation in food science Gatenby [23] stated "Correlations between moisture content and water activity can be developed through experimental measurement collection for individual products and the resulting moisture sorption isotherms can then be used to predict water activity and moisture content for a given product. There are no known alternatives to the tedious data development process".

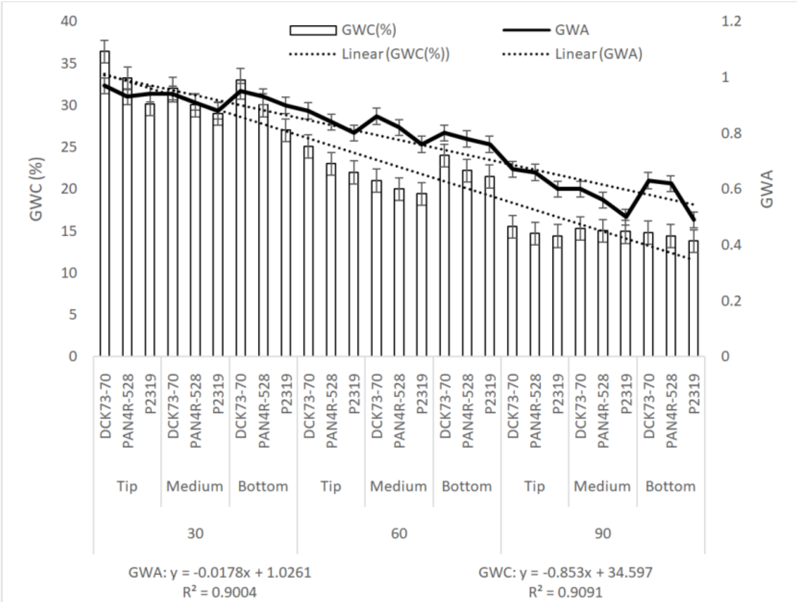
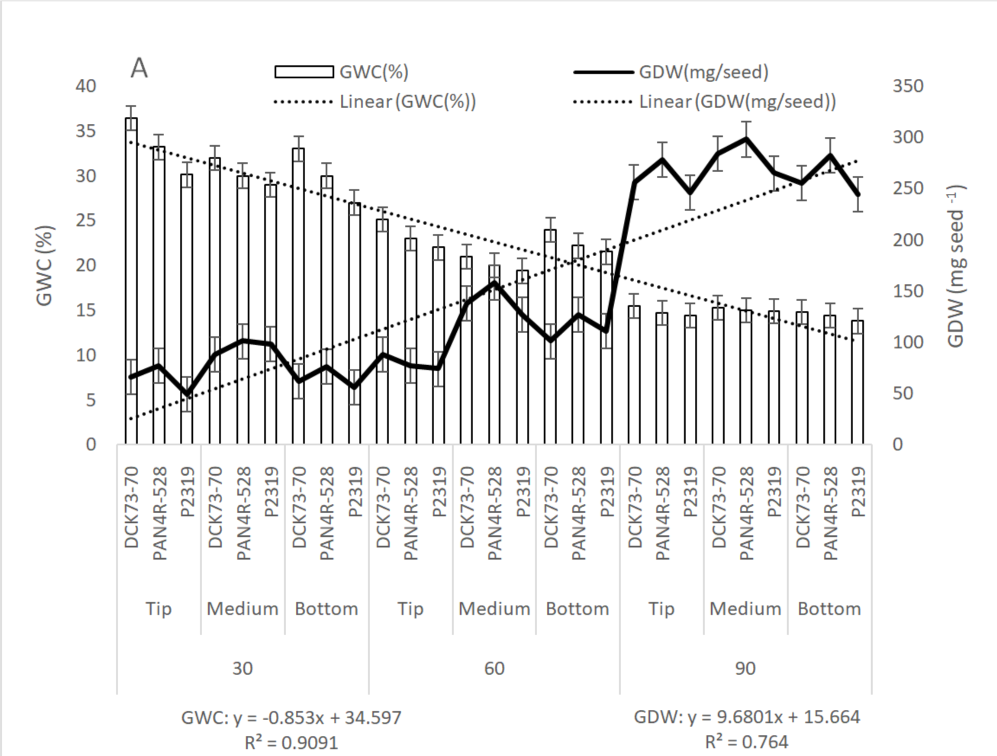
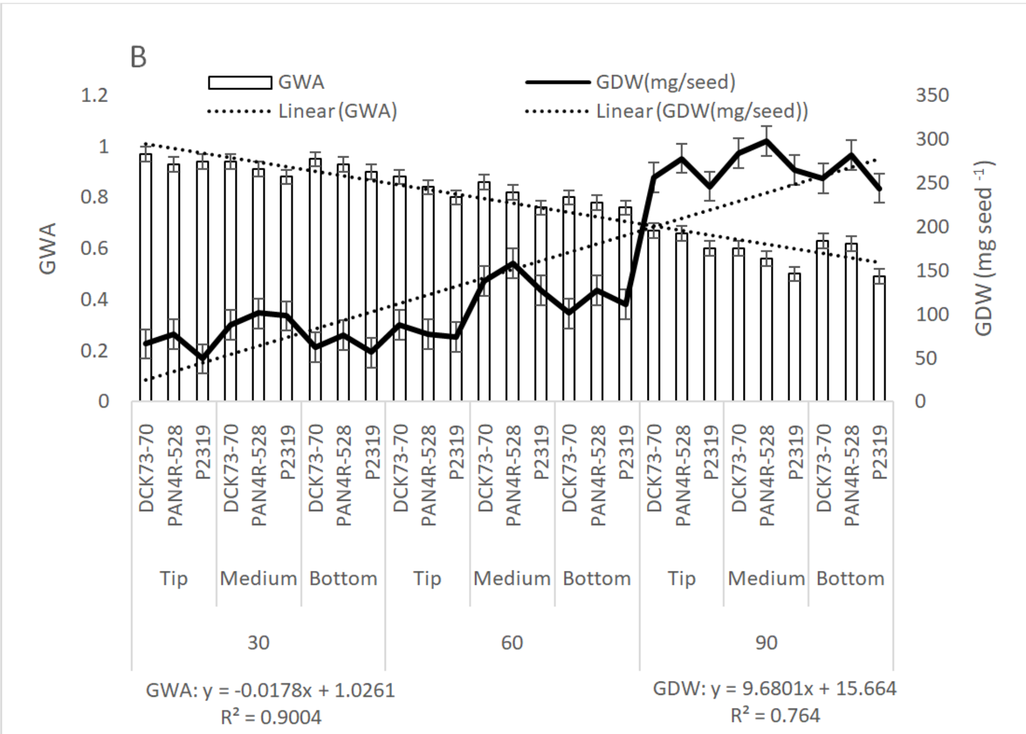
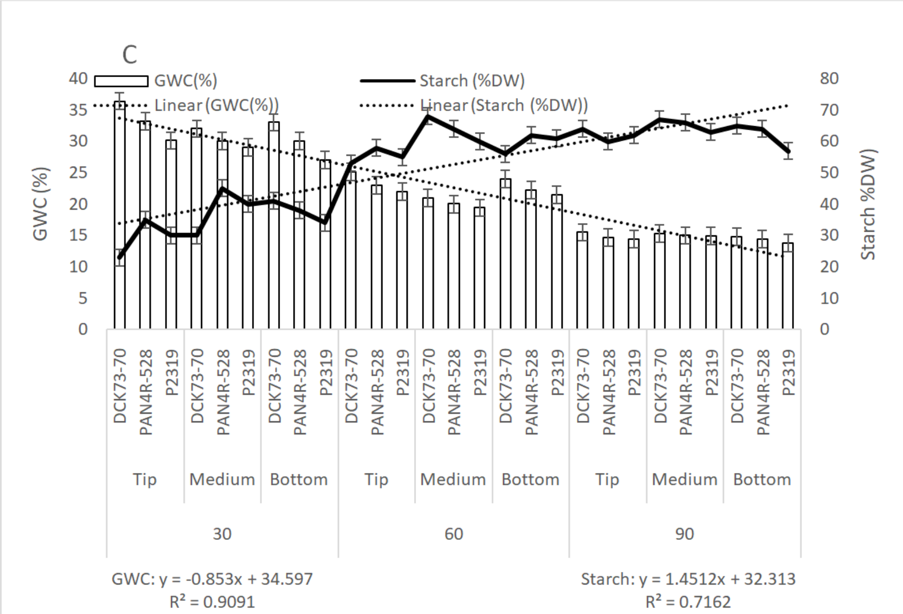


Figure 1. Relationship between grain water content (GWC) and water activity GWA) with respect to occurrence during maize seed development (30, 60 and 90 days after pollination). Seeds were harvested from three cob positions (Tip, Medium and Bottom) of three maize cultivars (DCK73-70; PAN4R-528 and P2319).

In the context of the objective of this study, it was necessary to explain the commonly known seed development index, dry matter accumulation, which is directly correlated with accumulation of the three major nutrients, carbohydrates, proteins and lipids, with both water content and water activity (Figure 2). To simplify the explanation, total dry matter was determined and the nutritive value of seeds was only measured in terms of total starch content (Figure 2). Results showed that the common seed development indices are common, regardless of position of the seed on the cob. However, it was evident that middle cob seeds are superior to those that are positioned in the tip and bottom. This was shown by early water accumulation associated with water activity being linked to more favourable grain dry matter and starch content for all cultivars (Figures 2). Although the accumulation of electrolytes was not directly measured, the water activity is a reliable index for their accumulation. Electrolytes can be represented by mineral elements, soluble carbohydrates and antioxidants[9]. Their accumulation has been shown to influence enzyme activity (24, 25) and seed health[10, 13]. Starch accumulation is a good indicator of yield potential (Figure 2).


A
GWC(%)
Linear (GWC(%))
GDW(mg/seed)
Linear (GDW(mg/seed))
GWC (%)
GDW (mg seed -1)
DCK73-70
PAN4R-528
P2319
Tip
Medium
Bottom
30
60
90
GWC: y = -0.853x + 34.597
R² = 0.9091
GDW: y = 9.6801x + 15.664
R² = 0.764


B
GWA
Linear (GWA)
GDW(mg/seed)
Linear (GDW(mg/seed))
GWA
GDW (mg seed -1)
DCK73-70
PAN4R-528
P2319
Tip
Medium
Bottom
30
60
90
GWA: y = -0.0178x + 1.0261
R² = 0.9004
GDW: y = 9.6801x + 15.664
R² = 0.764



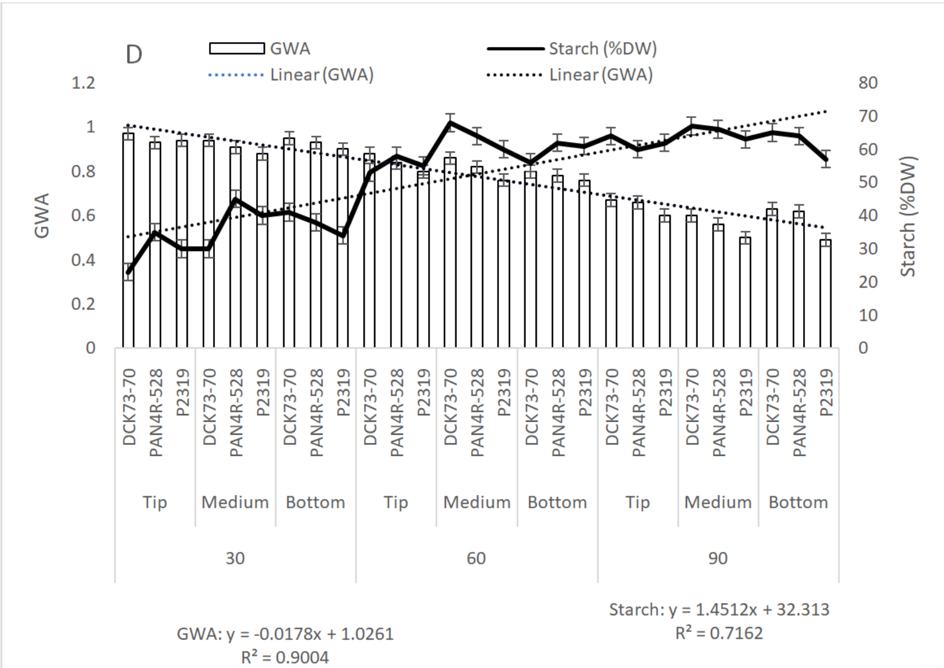


Figure 2. Relationship between grain water content (GWC) and water activity (GWA) with respect to accumulation of grain dry weight (GDW) (A and B), and total starch (C and D) during maize seed development (30, 60 and 90 days after pollination). Seeds were harvested from three cob positions (Tip, Medium and Bottom) of three maize cultivars (DCK73-70; PAN4R-528 and P2319).

The consistent relationship between position on the cob and seed quality was confirmed (Table 1). It was clear that the superior dry matter and electrolyte accumulation in medium cob seeds translates to better seed germination, vigour and yield potential (Table 1).

Table 1. Maize seed quality indices, germination (%), vigour index-1 and yield potential in response to temperature (cold = 15/20 ºC day/night; warm = 20/30 ºC day/night). Seeds were samples from three positions (Tip, Medium and Bottom) of the cob each measuring one third of the total length. Values sharing the same letter are not statistically different ($p \leq 0.05$).

Temperature	**Position**	**Cultivar**	**Germination**	**Vigour Index-1**	**Yield Potential**
Cold	Tip	*DCK73-70*	85a	2400a	65a
		PAN4R-528	83a	2800ab	70b
		P2319	84a	2600a	68ab
	Medium	*DCK73-70*	97bc	6000b	80c
		PAN4R-528	100c	6600b	85c
		P2319	95b	6400b	84c
	Bottom	*DCK73-70*	90b	2800ab	72b
		PAN4R-528	88ab	3000ab	75b
		P2319	89ab	2700ab	74b
Warm	Tip	*DCK73-70*	90b	5600b	76b
		PAN4R-528	92b	6000b	84c
		P2319	90b	5800b	80c
	Medium	*DCK73-70*	99bc	8000c	100de
		PAN4R-528	100c	8400c	110e
		P2319	98c	8200c	98d
	Bottom	*DCK73-70*	96bc	6000b	90d
		PAN4R-528	95b	6200b	95d
		P2319	94b	6000b	92d

Seed germination capacity has been accepted as significant index of hybrid potential for all cultivated crops [11]. This has been associated with the rate of dry matter accumulation in the early phase of seed development, which leads to a superior physiological maturity. The last phase of seed harvesting during this study occurred at physiological maturity. This is confirmed by the grain water content and maximum potential starch and dry matter accumulation. This positive relationship between yield potential and seed quality, in terms of both germination and vigour is an interesting finding which supports previous studies[12].

4. CONCLUSION

The findings of this study are preliminary in nature. However, there is a strong evidence to suggest that water can be viewed in different ways to confirm its influence on maize seed quality. The significance of this study is mainly that there is consistency in the relationship between grain water and seed quality indices regardless of seed position on the cob and environmental conditions during seed quality determination. While this study confirms that the superiority of middle cob grain for maize is associated with dry matter accumulation in general, there is also a strong suggestion that this may be related to nutrients. Future studies should confirm the response of soluble carbohydrate types, amino acids and proteins, as well as mineral elements which are most likely the reason for water activity observation in the current study. Since enzyme activities are influenced by the occurrence of electrolytes in different forms, such investigations may lead to better understanding of seed response to environment, for example seed dormancy, water stress and vernalisation in other species. Therefore, the limitation of this limitation of this study, which is a great opportunity for future studies is that the correlation between water content, water activity and the common seed quality indices does not include detailed biochemical analysis.

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