

DOI: <https://doi.org/10.21323/2618-9771-2026-9-2-154-161>



Received 30.10.2025

Accepted in revised 07.04.2026

Accepted for publication 14.04.2026

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Available online at <https://www.fsjour.com/jour>

Original scientific article

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PHYSICOCHEMICAL AND TECHNOLOGICAL PROPERTIES OF TORTILLA BREAD PRODUCED FROM MAIZE GRAINS CULTIVATED UNDER DROUGHT CONDITIONS

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KEYWORDS:

maize, rheological, tortilla bread, sensory, storage-quality

ABSTRACT

Bread production from maize is technologically challenging due to the poor viscoelastic properties of its dough. This study evaluated three maize cultivars cultivated under drought-exposed conditions with calcium foliar fertilization: one Egyptian cultivar (SCP3444, V1) and two early-maturing, high-yielding Nigerian cultivars (Sammaz-35, V2; EVDT, V3). These were compared with their respective control samples (Con1, Con2, Con3) were also evaluated to determine their effects on tortilla bread quality. Physicochemical, chromatic, and rheological properties of maize flour were evaluated, alongside sensory attributes and storage quality (AWRC) of the tortilla bread. Con1 and Con2 exhibited the highest values for 1000-kernel weight, hectoliter weight, and bulk density. The white maize cultivars, Con3 and V3 demonstrated the highest lightness (L) values, while protein content was significantly higher in Con2 and V2. Mineral analysis revealed that V2 had the highest calcium and zinc contents, whereas V3 was richest in iron. Rheological evaluation assessments suggested that V1 flour was optimal for producing softer tortilla bread, which exhibited enhanced tenderness after cooling. The most consumers' acceptable tortilla samples were TCon1, TV1, TCon2, and TV2, which were prepared from yellow maize. TV1 and TCon2 recorded the highest weight after baking. TV2 demonstrated the greatest loaf diameter increase before and after baking, while TV3 recorded the highest lightness and TCon2 the highest yellowness. For dietary reference intake in children (3–10 years), TV2 provided the highest contributions to daily requirements for protein, calcium, and zinc, whereas TV3 had the highest iron content. Regarding storage, TV1 showed the highest AWRC, indicating superior freshness and moisture retention, reflecting extended shelf life. These results highlight the potential for using drought-tolerant, calcium-fertilized maize cultivars to improve the technological, nutritional, and storage quality of tortilla bread.

Поступила 30.10.2026

Поступила после рецензирования 07.04.2026

Принята в печать 14.04.2026

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<https://www.fsjour.com/jour>

Научная статья

Открытый доступ

ФИЗИКО-ХИМИЧЕСКИЕ И ТЕХНОЛОГИЧЕСКИЕ СВОЙСТВА ТОРТИЛЬИ, ПРИГОТОВЛЕННОЙ ИЗ КУКУРУЗЫ, ВЫРАЩЕННОЙ В УСЛОВИЯХ ЗАСУХИ

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КЛЮЧЕВЫЕ СЛОВА: АННОТАЦИЯ

кукуруза, реологические свойства, тортилья, органолептические свойства, качество при хранении

Производство хлебобулочных изделий из кукурузы представляет собой технологически сложную задачу из-за низких вязкоупругих свойств кукурузного теста. В данном исследовании оценивались три сорта кукурузы, выращиваемых в засушливых условиях, с внесением внекорневой подкормки кальцием: один египетский сорт кукурузы (SCP3444, V1) и два раннеспелых высокоурожайных нигерийских сорта кукурузы (Sammaz-35, V2; EVDT, V3). Их сравнивали с соответствующими контрольными образцами, обозначенными как Con1, Con2, Con3, свойства которых также оценивались для определения влияния условий выращивания на качество тортильи. Были оценены физико-химические, хроматические и реологические свойства кукурузной муки, а также органолептические характеристики и качество продукта при хранении (щелочную водоудерживающую способность). Сорта кукурузы под кодом Con1 и Con2 показали самые высокие значения массы 1000 зерен, массы в гектолитре и насыпной плотности. Белые сорта кукурузы, Con3 и V3, продемонстрировали самые высокие значения светлости (L), в то время как содержание белка было значительно выше в сортах под обозначением Con2 и V2. Минеральный анализ показал, что мука из кукурузы под обозначением V2 имела самое высокое содержание кальция и цинка, тогда как мука из V3 была наиболее богата железом. Реологические исследования показали, что мука из V1 оптимальна для производства более мягкой тортильи, которая после охлаждения демонстрировала повышенную нежность. Наиболее потребительски приемлемыми образцами тортильи были TCon1, TV1, TCon2 и TV2, приготовленные из желтой кукурузы. Тортильи TV1 и TCon2 продемонстрировали наибольший вес после выпечки. TV2 продемонстрировала наибольшее увеличение диаметра лепешки до и после выпечки, в то время как TV3 отличалась наибольшей светлотой, а TCon2 — наибольшей желтизной. Что касается рекомендуемой суточной нормы потребления питательных веществ для детей (3–10 лет), TV2 внесла наибольший вклад в суточную потребность в белке, кальции и цинке, тогда как TV3 имела самое высокое содержание железа. Что касается хранения,

FOR CITATION: Aly, A. M., Mohammed, A. T., Abbas, M. S. (2026). Physico-chemical and technological properties of tortilla bread produced from maize grains cultivated under drought conditions. *Food Systems*, 9(1), 154–161. <https://doi.org/10.21323/2618-9771-2026-9-2-154-161>

ДЛЯ ЦИТИРОВАНИЯ: Али, А. М., Мохаммед, А. Т., Аббас, М. С. (2026). Физико-химические и технологические свойства тортильи, приготовленной из кукурузы, выращенной в условиях засухи. *Пищевые системы*, 9(1), 154–161. <https://doi.org/10.21323/2618-9771-2026-9-2-154-161>

TV1 показала самое высокое значение щелочной водоудерживающей способности, что указывает на превосходную свежесть и влагоудержание, отражающие способность данной тортильи выдерживать более длительный срок хранения. Эти результаты подтверждают потенциал использования засухоустойчивых, удобренных кальцием сортов кукурузы для улучшения технологических свойств, питательной ценности и продолжительности хранения тортилий.

1. Introduction

Maize (*Zea mays* L.) is one of the world's most important cereal crops, providing a major source of food and raw material for various industrial applications. Originally domesticated in Central America, maize was introduced to Europe and the other continents in the late 15th century. Due to its high adaptability, farmers have developed a vast range of genetically diverse maize varieties with various traits, adaptations, and scopes of applications. Today, maize is primarily used for animal feed in Europe. However, over the past five centuries, numerous maize-based food products have also emerged and become a part of traditional European cuisine [1]. In Egypt, the estimated maize production for 2023/2024 (October–September) is approximately 7.2 million metric tons (MMT), reflecting a decline of nearly 3.2% compared to 2022/2023. This reduction is primarily attributed to elevated temperatures during the growing season and increased insect infestation, which adversely affected kernel development and led to lower overall yields across the region between July and August [2]. Also, it's growing can be combined with other crops to produce staple foods that meet health standards, therefore improving the quality of life for people with gluten intolerance [3].

Drought defined as insufficient water availability, is one of the most common abiotic stresses affecting agriculture, especially in arid and semi-arid regions. Its occurrence and severity are forecast to increase as a result of global climate change, posing a serious threat to global crop productivity [4]. Drought is considered one of the most critical stress factors, which significantly reduces the yield and quality of major cereal crops [5]. Along with climate change leading to more frequent and severe droughts in many agricultural areas, a primary objective of adaptation strategies is to minimize the impact of drought on crop yields. Maize, in particular, is highly sensitive to water stress and has been the focus of numerous management improvements, including the recent development and adoption of drought-exposed varieties [6]. Maize is tall and broad-leaved plant, so extreme drought stress due to water deficit during its vegetation can cause leaves to curl, impede the growth and reproduction of maize. In addition, it can inhibit the induction of flowering in male flowers and cause factors that interfere with pollen development, which can greatly affect seedling formation, early plant growth, proper photosynthesis, reproductive growth, and yield [7]. Foliar application of calcium significantly improved the ability of maize plants to cope with drought stress. Among the evaluated cultivars, EVDT and SC-P3444 demonstrated the greatest tolerance to water deficiency, followed by Sammaz-35 [8]. Maize tortilla bread consumption varies significantly across regions. In the United States, the average annual per capita consumption reaches approximately 6 kg, while in Europe it is considerably lower, at around 0.3 kg per person [9]. Tortilla bread represents a fundamental component of the Mexican diet, with an average annual per capita consumption of 75 kg. They supply around 38.8% of daily protein needs, 49.1% of calcium requirements, and 45.2% of total daily caloric intake. Owing to their widespread popularity and flavors versatility, tortilla bread holds great potential as a vehicle for delivering bioactive and nutrient-rich compounds, which could play a vital role in reducing famine and malnutrition while promoting public health [10]. Traditionally, tortilla bread is crafted from native maize varieties and produced by ancient methods [11]. The main drawback of the nutritional composition of maize tortilla is the low quality of proteins attributed to its reduced lysin and tryptophan amino acids concentrations [12].

This study also aimed to evaluate the physical, chemical, and rheological properties of early-maturing, high-yielding maize varieties cultivated under drought conditions with foliar calcium fertilization and assess their suitability for producing high-quality gluten-free tortilla bread for individuals with gluten sensitivity or celiac disease. Quality assessment included sensory evaluation, storage stability, and the nutritional composition of the tortilla bread. The results may also contribute to guiding the selection of maize genotypes with improved nutritional and functional traits for their potential use in maize cultivar breeding programs aimed at improving maize quality under stress conditions.

2. Objects and methods

2.1. Objects

Three maize cultivars were used in this study: an Egyptian commercial cultivar (SC-P3444) and two early-maturing, high-yielding Nigerian cultivars (Samaz-35 and EVDT), which were obtained from Agricultural

Experimental and Research Station, Faculty of Agriculture, Cairo University, Giza, Egypt. These cultivars were cultivated under natural conditions as a control samples, and were relevantly coded as Con1, Con2, and Con3, and the same cultivars were grown under drought-exposed conditions using calcium foliar fertilization and were coded as V1, V2, and V3. Salt, baking soda, sugar, and oil were purchased from a local market, Cairo, Egypt. All other used chemicals were of the analytical reagent grade.

2.2. Weight of 1000- kernels

The 1000-kernel weight was measured by weighing 100 cleaned kernels in triplicate and extrapolating the average weight by the standard methods of ISO 520 [13].

2.3. Hectoliter weight

Hectoliter weight was determined by standard methods of ISO 7971-1 [14], and expressed as Kg/hL.

2.4. Bulk density

A maize kernel was placed in a 100 ml graduated cylinder, and both its volume and weight were measured. Bulk density was then calculated according to the method described by Wongsu et al. [15] as follows:

$$\text{Bulk density} = \frac{\text{weight of maize (g)}}{\text{volume of maize (cm}^3\text{)}}. \quad (1)$$

2.5. Maize kernels preparation

The initial moisture content of whole maize kernels was estimated using a laboratory oven (Bongard, France) at 105 °C for 3 hours until the weight was constant, according to the AOAC [16] standard method. Moisture content of maize kernels was adjusted to 14% by adding the calculated amount of water using the equation (2). The calculated water was added individually to maize grains placed in polyethylene bags. Each bag was manually mixed for 3 minutes to ensure uniform moisture distribution. After sealing, the bags were stored at 25 °C for 16 hours to allow moisture equilibration throughout the grains, following the method of Chowdhury et al. [17] with some modification. The kernels were then partially dried by spreading them on trays and air-drying them for 1 hour. The kernels were crushed to estimate the final moisture content using the same method as for the initial moisture content. The conditioned grains were then milled using a laboratory fractionation roller mill (Brabender Duisburg, Germany) to produce fine whole meal flour (approximately 80 mesh). The flour was packed in polyethylene bags and stored in a deep freezer until use.

$$Q = \frac{W_a (M_b - M_i)}{100 - M_b}, \quad (2)$$

where: Q — is the amount of water added, g; W_a — is the sample initial mass, g; M_i — is the initial moisture content of the sample, %; M_b — is the desired moisture content of the sample, %.

2.6. Color measurement

The color of maize kernel flour and the color of tortilla bread were evaluated following the procedure described by McGuire [18] using a hand-held tristimulus reflectance colorimeter model CR-400, Konica Minolta, Japan). The measured color parameters included L^* (ranging from 0 = black to 100 = white), a^* (indicating the range from red [+] to green [–] axis), and b^* (indicating the range from yellow [+] to blue [–] axis).

2.7. Chemical composition

Crude protein, fat, crude fiber, and ash content of maize flour and tortilla bread were determined according to AOAC [16]. Carbohydrate was calculated by difference on dry weight

$$\text{Available carbohydrate} = 100 - (\text{protein} + \text{fat} + \text{fiber} + \text{ash}) \quad (3)$$

2.8. Minerals content

The contents of Ca, Zn, and Fe in the maize flour and tortilla bread were analyzed using an atomic absorption spectrophotometer Model 300 (Perkin Elmer, USA), following the procedures outlined by AOAC [16].

2.9. Rheological properties (Mixolab analysis)

The rheological properties of maize flour dough were analyzed using a device Mixolab (Chopin Technologies, France). The measured parameters included water absorption (C1), dough development time, dough

stability, protein weakening (C2), starch gelatinization (C3), hot starch paste stability (C4), and retrogradation (C5), following the standard method AACCC [19].

2.10. Tortilla bread preparation

Six tortilla bread samples (TCon1, TV1, TCon2, TV2, TCon3, and TV3) were prepared as outlined in Table 1, following the method described by Rendón-Villalobos et al. [20] with slight modifications. The samples were prepared using 100% maize flour derived from the same maize cultivars cultivated under normal conditions (control groups) and drought-exposed conditions with calcium foliar fertilization (experimental groups). The maize flour was combined with water to form dough, which was gelatinized over direct heat for approximately 10–15 minutes and then allowed to cool. Subsequently, fat, salt, and hydrocolloids were incorporated, and the mixture was left to rest for 10 minutes. The dough was then divided into 50 g portions and shaped into discs approximately 2 mm thick and 15 cm in diameter. The samples were baked on a hot grill at around 250 °C for 27 seconds on one side and 30 seconds on the other, then turned on both sides until puffed, and finally cooled to room temperature. After sensory evaluation, the tortilla bread was packaged in polyethylene bags and stored at room temperature for 24, 48, and 72 hours before analysis.

Table 1. Formula of tortilla bread

Таблица 1. Рецепт тортильи

Ingredients	Formula, g/100 g					
	TCon1	TV1	TCon2	TV2	TCon3	TV3
Maize flour	100	100	100	100	100	100
Salt	1.5	1.5	1.5	1.5	1.5	1.5
Oil	6	6	6	6	6	6
Baking soda (sodium bicarbonate)	4	4	4	4	4	4
Xanthan gum	0.6	0.6	0.6	0.6	0.6	0.6
Water	The amount of water is relevant to the amount of its absorption using the Mixolab device					

2.11. Total caloric value (TCV)

The total caloric value of tortilla bread was calculated by Marero et al. [21], as follows:

$$\text{TCV (kcal/100 g)} = 4 (\text{Protein}) + 4 (\text{Carbohydrate}) + 9 (\text{Fat}). \quad (4)$$

2.12. Sensory evaluation of tortilla bread

The sensory evaluation of six tortilla bread samples was conducted by a trained panel consisting of 10 members selected from the staff of the Food Technology Research Institute, Agricultural Research Center, Giza, Egypt. The evaluation of tortilla bread included assessments of its general appearance, color, roundness (sphericity), taste, flavor, which made up the overall consumer acceptability, with each attribute scored 20, resulting in a total score of 100, as described by Cardona-Herrera et al. [22].

2.13. Physical characteristics of tortilla bread

Physical properties of six tortilla bread samples were evaluated for their loaves weight (g), and their diameter (cm). Tortilla bread weight was measured using a digital laboratory weighing scale (Model: Sartorius TE6101, Germany), while diameter was evaluated with a digital Vernier Caliper (Fuzhou Conic Industrial Co., Ltd., China) according to Enríquez-Castro et al. [23].

2.14. Dietary reference intake (DRI) of tortilla bread

The dietary reference intake was estimated according to DRI [24].

2.15 Alkaline water retention capacity (AWRC) of tortilla bread:

Alkaline water retention capacity (AWRC) was determined according to Licciardello et al. [25] with some modifications and calculation as follows.

$$\text{AWRC (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad (5)$$

where: W_1 — is the weight of tube containing the dry sample; W_2 — is the weight of tube containing the dripped sample.

Analyses were conducted in duplicate at each day of the experimental period (0, 1, 2, and 3 days).

2.16. Statistical analysis

Data were analyzed using F. test via one-way ANOVA ($P \leq 0.05$), Duncan's multiple range tests for means comparison was applied using Cos-tas statistical software based on a probability level according to Steel and Torrie [26].

3. Results and discussion

3.1. Physical characteristics and color of maize cultivars

Table 2 provides an overview of the physical and color characteristics of various maize cultivars. Physical parameters of the maize kernel are critical in selecting maize cultivar suitable for tortilla bread production due to their influence on processing functionality and cooking behavior [27]. The 1,000-kernel weight varied between 262 and 339 g, while the hectoliter weight ranged from 131 to 173 kg/hl. Notably, the cultivars cultivated under drought-exposed conditions using calcium foliar fertilization (V1, V2, and V3) exhibited lower 1,000-kernel weight, hectoliter weights, and bulk density than their respective control counterparts cultivated under normal conditions (Con1, Con2, and Con3). Bulk density was observed to range from 2.62 g/cm³ for V3 to 3.40 g/cm³ for Con1. Among the cultivars cultivated under drought-exposed conditions using calcium foliar fertilization, V1 featured the highest 1,000-kernel weight, hectoliter weight, and bulk density. These findings align with the previous studies [8,28,29].

Table 2 illustrates the color parameters of maize samples, including lightness (L^*), redness (a^*), and yellowness (b^*). Significant differences were observed in lightness values between the control maize cultivars and those cultivated under drought-exposed conditions with calcium foliar fertilization. Among the samples, white maize cultivars Con3 and V3 featured the highest L^* values (87.96 and 87.87, respectively) and the lowest redness (0.89 and 0.91, respectively), compared to the other samples. Yellowness (b^*) values, which were notably higher in Con1, V1, Con2, and V2, indicate their yellow color. The observed differences in color among maize cultivars may be attributed to genetic variation [30]. Kljak et al. [31] found a strong positive correlation between total carotenoid content and the b^* (yellowness) value.

3.2. Chemical composition and mineral content for maize cultivars

The chemical composition and mineral content of different maize cultivars are presented in Table 3. The data reveal significant differences between the maize cultivar under drought-exposed conditions using calcium foliar fertilization (V1, V2, and V3) and their controls, which were cultivated under normal conditions (Con1, Con2, and Con3). All maize cultivars cultivated under drought-exposed conditions using calcium foliar fertilization (V1, V2, and V3) exhibited higher protein, fiber, and fat contents, Ca, Zn, and Fe, while available carbohydrate content decreased compared to their respective controls (Con1, Con2, and Con3). Protein content was significantly higher in the cultivars Con2 and V2, reaching 9.44% and 9.89%, respectively, while the lowest protein content (6.35%) was observed in the cultivar Con3. Maize cultivars Con1, V1, V2, and V3 exhibited the highest ash content. V1 also exhibited the highest crude

Table 2. Physical characteristics and color of maize cultivars

Таблица 2. Физические характеристики и цвет сортов кукурузы

	Physical characteristics			Color		
	1000-weight Kernel, g	Hectoliter weight, kg/hl	Bulk density, g/cm ³	L^*	a^*	b^*
Con1	337.5 ± 0.5 ^a	173.0 ± 0.71 ^a	3.40 ± 0.08 ^a	84.41 ± 0.91 ^b	−1.84 ± 0.02 ^c	20.27 ± 0.38 ^a
V1	308.75 ± 0.25 ^b	154.37 ± 0.44 ^b	3.08 ± 0.09 ^b	84.29 ± 0.77 ^b	−1.94 ± 0.02 ^d	20.51 ± 0.45 ^a
Con2	339.0 ± 0.33 ^a	169.5 ± 0.50 ^a	3.39 ± 0.01 ^a	82.33 ± 0.12 ^c	−1.69 ± 0.01 ^a	20.01 ± 0.69 ^a
V2	274.0 ± 0.71 ^{cd}	137.0 ± 0.75 ^{cd}	2.76 ± 0.11 ^c	82.78 ± 0.01 ^c	−1.76 ± 0.03 ^b	19.61 ± 0.53 ^a
Con3	277.75 ± 0.55 ^c	138.87 ± 0.60 ^c	2.77 ± 0.02 ^c	87.96 ± 0.64 ^a	0.89 ± 0.01 ^e	10.47 ± 0.39 ^b
V3	262.0 ± 0.44 ^d	131.0 ± 0.55 ^d	2.62 ± 0.03 ^d	87.87 ± 0.45 ^a	0.91 ± 0.01 ^e	10.51 ± 0.35 ^b

Con1, Con2, and Con3 as control samples of three cultivars as follows: SCP3444, Sammaz-35, and EVDT, respectively. V1, V2, and V3 are three cultivars cultivated under drought-exposed conditions using calcium foliar fertilization as follows: SCP3444, Sammaz-35, and EVDT, respectively. Means with different letters in the same column are significantly different at $P \leq 0.05$.

Table 3. Chemical composition (g/100g sample) and mineral content (mg/100g) for maize flour

Таблица 3. Химический состав (г/100 г образца) и содержание минералов (мг/100 г) в кукурузной муке

	Chemical composition, g/100 g				Mineral content, mg/100 g			
	Protein	Ash	Crude fiber	Fat content	Carbohydrate (AC)	Ca	Zn	Fe
Con1	6.81±0.20 ^{bc}	1.76±0.08 ^a	1.38±0.06 ^b	3.56±0.16 ^{cd}	86.49±0.29 ^b	51.61±0.15 ^d	4.13±0.02 ^b	2.89±0.01 ^e
V1	7.10±0.19 ^b	1.79±0.01 ^a	1.56±0.09 ^a	3.66±0.04 ^c	85.89±0.19 ^{bc}	61.15±0.55 ^b	4.27±0.13 ^{ab}	3.28±0.02 ^d
Con2	9.44±0.09 ^a	1.61±0.01 ^{ab}	1.23±0.02 ^d	3.81±0.55 ^b	83.91±0.49 ^d	51.11±0.21 ^d	4.09±0.11 ^b	2.84±0.04 ^e
V2	9.89±0.13 ^a	1.75±0.27 ^a	1.26±0.01 ^c	4.54±0.54 ^a	82.56±0.56 ^e	67.86±0.11 ^a	4.35±0.26 ^a	5.59±0.11 ^c
Con3	6.35±0.11 ^c	1.42±0.02 ^b	1.25±0.07 ^d	3.84±0.13 ^b	87.14±0.24 ^a	38.46±0.22 ^e	3.53±0.05 ^c	7.41±0.13 ^b
V3	7.01±0.11 ^b	1.71±0.10 ^a	1.32±0.05 ^c	4.40±0.39 ^{ab}	85.56±0.31 ^c	57.21±0.11 ^c	4.32±0.12 ^{ab}	10.15±0.0 ^a

Con1, Con2, and Con3 as control samples of three cultivars as follows: SCP3444, Sammaz-35, and EVDT, respectively. V1, V2, and V3 are three cultivars cultivated under drought-exposed conditions using calcium foliar fertilization as follows: SCP3444, Sammaz-35, and EVDT, respectively. Means with different letters in the same column are significantly different at $P \leq 0.05$. AC: available carbohydrate.

fiber content at 1.56%. Fat content was significantly higher in cultivar V2 (4.54%) and the lowest in Con1 (3.56%). Con3 recorded the highest available carbohydrate levels among the cultivars, whereas V2 showed the lowest. The highest levels of these minerals were recorded in V2, with 67.86 mg/100 g for Ca and 4.35 mg/100 g for Zn, while the highest Fe content (10.15 mg/100 g) was found in V3. These results were close to the results of Naem et al. [32] who indicated that the foliar application of calcium under water deficit conditions improved the nutrient content of grains, increasing the nitrogen, calcium, iron, and zinc contents of grains. Likewise, foliar calcium spraying on maize leaves reduced oxidative damage and maintained nitrogen metabolism, which increased protein content under stress [8].

3.3. Rheological properties (Mixolab analysis) of maize flour

The rheological behavior of different maize cultivars cultivated under drought-exposed conditions using calcium foliar fertilization (V1, V2, V3) and Con1 sample as the control was investigated using the Mixolab. The rheological characteristics of dough are presented in the Table 4. Mixolab results revealed significant differences between the studied maize cultivars. Water absorption (WA) is a key factor influencing dough properties and the baking process, as it directly impacts the volume and quality of the baked products. In this study, WA ranged from 51.90% to 60.80%. V2 sample exhibited the highest value (60.80%), compared to the other samples. This suggests that V2 flour possesses a higher hydration capacity, likely due to its greater protein content or broken-down starch content, both of which strongly bind water. These findings align with Hadnadev et al. [33] and Moreira et al. [34], who reported that increased WA results from protein molecules binding water until a suitable consistency is reached. Similarly, Xu et al. [35] and Awolu [36] noted that protein-rich flour absorb more water than low-protein or starch-rich systems. Variations in WA can also be attributed to grain hardness, damaged starch levels, protein content, arabinoxylan concentration, and particle size [37].

Dough development time (DDT) is defined as the interval from the beginning of water addition to the point at which the dough reaches optimal texture. Among the samples, V2 exhibited the longest DDT (1.63 min), indicating that it required more time for complete hydration compared to the others [38]. A longer DDT reflects the formation of a stronger protein network, which is associated with improved dough handling properties [39]. In contrast, the other samples (Con1, V1, V3) showed equal DDT values of 1.28 min. These values are comparable to those reported for certain gluten-free commercial flours, such as rice flour (1.13 min) [34].

Stability time (ST) measures the dough's resistance to kneading, reflecting its ability to withstand mechanical mixing and thermal stress without structural breakdown. In the present study, ST values varied significantly among the samples, with V2 exhibiting the highest value (6.90 min) and Con1 the lowest (3.79 min). The longer ST observed in V2 indicates superior dough stability, which is advantageous for maintaining dough integrity during processing. Such resistance to mechanical breakdown is particularly desirable in tortilla production, where an elastic and cohesive dough properties are essential for achieving optimal texture and kneading properties [38,40].

Maximum torque (C1) was uniform in all samples (1.12 Nm) but Con1, which was slightly lower (1.10 Nm).

C2 torque represents the protein weakening phase, indicating the extent to which the protein network resists degradation under combined mechanical and thermal stress. In this study, V2 exhibited the highest C2 value (0.89 Nm), followed closely by V1 (0.88 Nm), while Con1 recorded the lowest (0.84 Nm). A higher C2 value reflects greater thermal stability and integrity of the protein network, which contributes to improved dough strength and handling during processing [41].

C3 torque reflects starch gelatinization, representing the swelling capacity of starch granules and the resulting changes in dough functional and rheological properties during heat processing relative to protein stability. V2 had the highest gelatinization peak (2.12), showing better starch swelling capacity. This enhanced gelatinization potential may contribute to increased product volume and improved crumb texture in the baked goods, as starch swelling plays a critical role in gas retention and final product quality. The increase in C3 torque is an indicator of starch gelatinization during heating and cooking [42]. The decrease in C3 torque could be due to the non-starch components (lipids, proteins, and dietary fibers) present in the flour that can compete with starch for water absorption, thus limiting the swelling and gelatinization of starch during cooking [43].

C4 torque measures hot gel stability, reflecting the ability of gelatinized starch to withstand high temperatures without structural breakdown. The gelatinized starch stability (C4) was maintained at 2.89 Nm in all samples except V1, which showed a marked decrease to 1.76 Nm. A lower C4 value indicates reduced starch gel stability. Low amylose content can lead to a more fluid gel structure, thereby contributing to the decrease in C4 torque [44].

C5 torque reflects the extent of starch retrogradation during the cooling phase. Among the tested samples, V1 exhibited the lowest degree of starch retrogradation and recrystallization (3.97 Nm), indicating better freshness retention, while Con1 had the highest C5 torque (5.05 Nm), implying faster retrogradation and reduced shelf-life quality, which is undesirable for tortilla bread due to reduced freshness. The reduction in retrogradation may be influenced by particle size, where smaller particle sizes enhance α -amylase activity, thereby reducing the C5 value. As a result, starch retrogradation is limited, contributing to improved bread freshness retention [44]. The long shelf life of a product is correlated with its low retrogradation value [45]. Retrogradation is influenced the amylose/amylopectin ratio, and the average chain length of amylose and amylopectin [41]. The Mixolab evaluation in this study indicates that V1 is suitable for producing softer tortilla bread with extended flexibility. This is attributed to its low C5 value, which promote the production of soft, elastic tortilla bread that maintain its tenderness after cooling.

Table 4. Mixolab parameters of maize flour

Таблица 4. Показатели кукурузной муки, измеренные устройством Mixolab

Mixolab parameters	Con1	V1	V2	V3
WA, %	51.90 ^d	58.80 ^b	60.80 ^a	53.80 ^c
DDT, min	1.28 ^b	1.28 ^b	1.63 ^a	1.28 ^b
ST, min	3.79 ^d	5.22 ^b	6.90 ^a	4.79 ^c
C1 torque, Nm	1.10 ^b	1.12 ^a	1.12 ^a	1.12 ^a
C2 torque, Nm	0.84 ^d	0.88 ^b	0.89 ^a	0.85 ^c
C3 torque, Nm	1.85 ^d	1.88 ^b	2.12 ^a	1.86 ^c
C4 torque, Nm	2.89 ^a	1.76 ^b	2.89 ^a	2.89 ^a
C5 torque, Nm	5.05 ^a	3.97 ^c	4.45 ^b	4.45 ^b

WA — water absorption (14% moisture basis); DDT — dough development time; ST — stability time; C1 torque — maximum dough torque to determine water absorption; C2 torque — protein weakening as a function of mechanical work and temperature; C3 torque — starch gelatinization; C4 torque — hot gel stability; C5 torque — starch retrogradation in the cooling phase.

Con1: the SCP3444 cultivar as control sample. V1, V2, and V3: three cultivars cultivated under drought-exposed conditions using calcium foliar fertilization as follows: SCP3444, Sammaz-35, and EVDT, respectively. Means with different letters in the same column are significantly different at $P \leq 0.05$.

3.4. Sensory evaluation of tortilla bread

Tortilla bread is considered an excellent source of energy due to its high carbohydrate content. Moreover, their growing popularity is attributed to their suitability as a gluten-free food option, thus making them particularly beneficial for the individuals with gluten intolerance or celiac disease [46]. Table 5 shows the sensory attributes of tortilla bread samples made from different maize cultivars. The results indicate that the most acceptable tortilla bread samples were TCon1, TV1, TCon2, and TV2 prepared from yellow maize cultivars in terms of their appearance, color, and roundness. The highest taste and overall acceptability scores were in TV1, TCon2, and TV2 compared to all samples. In addition, TV1 and TV2 were the most acceptable in terms of odor. Conversely, the white tortilla made from TCon3 and TV3 received the lowest scores across all parameters, with TV3 scoring the least acceptable in all evaluated attributes.

Table 5. Sensory evaluation of tortilla bread
Таблица 5. Органолептические свойства тортильи

	General appearance (20)	Color (20)	Roundness (20)	Taste (20)	Odor (20)	Overall acceptability (100)
TCon1	19.45 ^a	19.50 ^a	19.45 ^a	19.44 ^b	19.39 ^b	97.23 ^b
TV1	19.85 ^a	19.89 ^a	19.90 ^a	19.85 ^a	19.83 ^a	99.32 ^a
TCon2	19.90 ^a	19.89 ^a	19.90 ^a	19.88 ^a	19.79 ^{ab}	99.36 ^a
TV2	19.93 ^a	19.80 ^a	19.90 ^a	19.91 ^a	19.89 ^a	99.43 ^a
TCon3	18.56 ^b	17.55 ^b	18.20 ^b	18.10 ^c	17.29 ^c	89.70 ^c
TV3	17.65 ^c	17.35 ^b	18.05 ^b	17.60 ^d	17.33 ^c	87.98 ^d

TCon1, TCon2, and TCon3 are tortilla breads as control samples of three cultivars as follows: SCP3444, Sammaz-35, and EVDT, respectively, and TV1, TV2, and TV3 are tortilla breads of three cultivars cultivated under drought-exposed conditions using calcium foliar fertilization as follows: SCP3444, Sammaz-35, and EVDT, respectively. Means with different letters in the same column are significantly different at $P \leq 0.05$.

3.5. Physical properties of tortilla bread

Table 6 shows the physical properties of tortilla bread, including loaf weight and diameter before and after baking, as well as the color measurement after baking. The results indicated no significant differences in the weight of the loaves before baking; however, significant differences were observed after their baking. TCon1 recorded the lowest loaf weight (23.43 g) after baking, while both TV1 and TCon2 recorded the highest

weight. Significant differences were observed in loaves diameters before and after baking. TV2 showed the greatest increase in loaf diameter (13.70 cm and 12.06 cm, respectively) before and after baking among all tortilla bread samples. Ahmed et al. [47] reported that the diameter measured before and after baking reflects the dough's ability to expand or resist to shrinking during the loaf formation process.

The color of a food product plays a crucial role in influencing consumer acceptance, purchasing behavior, and decision-making, as the consumers often associate specific colors with particular flavors and perceived quality attributes [48,49]. Table 6 presents the color measurements of tortilla bread after baking. Among the samples, TV3 showed the highest lightness ($L = 61.71$) and the lowest redness ($a^* = 0.81$), while TCon2 recorded the highest yellowness ($b = 41.42$). TV1 also showed increased redness ($a^* = 1.92$), indicating a darker, more browned surface. These color variations can be attributed to starch gelatinization and the Maillard reaction between reducing sugars and proteins during baking, both of which contribute significantly to crust formation and the final product appearance [27].

3.6. Chemical composition of tortilla bread

Table 7 shows the chemical composition of tortilla bread prepared from different maize cultivars, revealing significant differences among all samples. Tortilla samples TV1, TV2, and TV3, produced from maize cultivated under drought-exposed conditions with calcium foliar fertilization, showed significantly higher levels of protein, calcium (Ca), zinc (Zn), and iron (Fe) than their counterparts TCon1, TCon2, and TCon3, produced from maize cultivated under normal conditions (control). Among the samples, TCon1 recorded a higher fat content (7.03%), and TV1 showed significantly higher ash and crude fiber contents, reaching 1.63% and 1.82%, respectively. TV2 showed significantly higher levels of protein, calcium, and zinc than the other samples. These findings are consistent with the previous studies [8,32].

TCon3 showed a significant decrease in fat content (3.86%), while it had the highest total carbohydrate content. TV3 increased significantly in iron content among all samples. In addition, lower protein levels were observed in all tortilla bread samples compared to the original maize flour, as shown in Table 3. This decrease is likely caused by protein degradation and structural changes during baking. As the starch gelatinizes, the elevated baking temperatures lead to protein unfolding and aggregation, thereby decreasing the measurable protein fraction in the final product [27,29].

As illustrated in the Figure 1, the highest total caloric values were recorded in tortilla bread made from TCon1 (422.31 kcal/100 g) followed by TV3 (420.21 kcal/100 g), exceeding the other samples.

Table 6. Physical properties tortilla bread

Таблица 6. Физические свойства тортильи

	Physical properties						
	Before baking		After baking		Color after baking		
	Loaf weight (g)	Diameter (cm)	Loaf weight (g)	Diameter (cm)	L^*	a^*	b^*
TCon1	35.48 ± 0.07 ^a	13.0 ± 0.5 ^b	23.43 ± 0.29 ^c	11.30 ± 0.11 ^d	57.73 ± 0.34 ^b	1.62 ± 0.02 ^b	37.33 ± 0.53 ^c
TV1	36.38 ± 0.30 ^a	12.66 ± 0.28 ^b	26.76 ± 0.41 ^a	11.7 ± 0.23 ^b	59.85 ± 0.04 ^{ab}	1.92 ± 0.01 ^a	38.36 ± 0.50 ^b
TCon2	36.25 ± 0.52 ^a	13.23 ± 0.40 ^{ab}	26.86 ± 0.19 ^a	11.26 ± 0.17 ^d	54.31 ± 0.04 ^c	1.40 ± 0.01 ^d	41.42 ± 0.51 ^a
TV2	36.20 ± 0.55 ^a	13.7 ± 0.43 ^a	25.02 ± 0.39 ^b	12.06 ± 0.25 ^a	54.17 ± 0.53 ^c	1.49 ± 0.02 ^c	35.28 ± 0.47 ^d
TCon3	35.57 ± 0.14 ^a	13.3 ± 0.34 ^{ab}	23.97 ± 0.25 ^{bc}	11.66 ± 0.05 ^{bc}	60.64 ± 0.19 ^{ab}	1.02 ± 0.01 ^e	25.41 ± 0.45 ^f
TV3	35.54 ± 0.13 ^a	13.06 ± 0.11 ^{ab}	24.82 ± 0.53 ^{bc}	11.40 ± 0.10 ^{cd}	61.71 ± 0.42 ^a	0.81 ± 0.01 ^f	33.65 ± 0.32 ^e

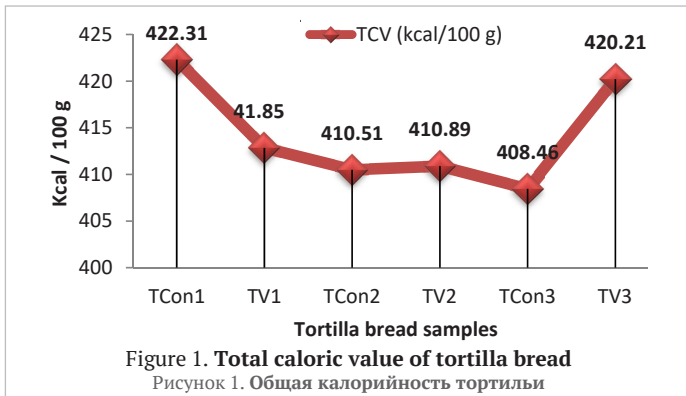
TCon1, TCon2, and TCon3 are tortilla breads as control samples of three cultivars as follows: SCP3444, Sammaz-35, and EVDT, respectively, and TV1, TV2, and TV3 are tortilla breads of three cultivars cultivated under drought-exposed conditions using calcium foliar fertilization as follows: SCP3444, Sammaz-35, and EVDT, respectively. Means with different letters in the same column are significantly different at $P \leq 0.05$.

Table 7. Chemical composition of tortilla bread

Таблица 7. Химический состав тортильи

	Chemical composition (g/100g) on dry basis					Mineral content, mg/100 g		
	Protein	Ash	Crude fiber	Fat content	Carbohydrate (AC)	Ca	Zn	Fe
TCon1	6.08 ± 0.27 ^d	1.55 ± 0.01 ^b	1.66 ± 0.16 ^b	7.03 ± 0.14 ^a	83.68 ± 0.11 ^d	31.66 ± 0.11 ^f	3.34 ± 0.23 ^d	1.61 ± 0.11 ^d
TV1	6.75 ± 0.05 ^c	1.63 ± 0.08 ^a	1.82 ± 0.29 ^a	5.33 ± 0.11 ^c	84.47 ± 0.19 ^b	38.44 ± 0.43 ^d	4.17 ± 0.22 ^b	1.84 ± 0.23 ^c
TCon2	9.35 ± 0.39 ^b	1.41 ± 0.01 ^d	1.50 ± 0.12 ^c	4.43 ± 0.10 ^d	83.31 ± 0.19 ^{de}	46.43 ± 0.09 ^c	3.50 ± 0.18 ^c	1.61 ± 0.12 ^d
TV2	9.79 ± 0.23 ^a	1.41 ± 0.27 ^d	1.48 ± 0.21 ^c	4.49 ± 0.22 ^d	82.83 ± 0.16 ^e	52.29 ± 0.10 ^a	4.25 ± 0.10 ^a	2.32 ± 0.20 ^b
TCon3	5.98 ± 0.18 ^d	1.38 ± 0.02 ^d	1.33 ± 0.17 ^d	3.86 ± 0.23 ^e	87.45 ± 0.14 ^a	35.46 ± 0.20 ^c	3.45 ± 0.15 ^d	1.19 ± 0.13 ^c
TV3	6.97 ± 0.04 ^c	1.50 ± 0.10 ^c	1.36 ± 0.15 ^d	6.33 ± 0.20 ^b	83.84 ± 0.21 ^c	51.36 ± 0.21 ^b	4.08 ± 0.26 ^b	2.43 ± 0.22 ^a

TCon1, TCon2, and TCon3 are tortilla breads as control samples of three cultivars as follows: SCP3444, Sammaz-35, and EVDT, respectively, and TV1, TV2, and TV3 are tortilla breads of three cultivars cultivated under drought-exposed conditions using calcium foliar fertilization as follows: SCP3444, Sammaz-35, and EVDT, respectively. Means with different letters in the same column are significantly different at $P \leq 0.05$. AC: A carbohydrate.



3.7. Dietary reference intake (DRI) of tortilla bread

DRI of tortilla bread samples prepared from various maize cultivars, targeting children aged 3–10 years, based on a 100 g portion according to the Dietary Reference Intakes (DRI, 2002/2005) [24], is presented in the Table 8. The TV2 tortilla sample provided the highest protein share, at 34.96% per 100 g, followed by the TCon2 sample, which provided 33.39% per 100 g tortilla based on a recommended dietary allowance of 28 g per day. The TCon3 sample showed the highest share of carbohydrate content, at 67.26% per 100 g of tortilla, based on a recommended dietary allowance of 130 g per day. TCon1 and TV3 showed the highest caloric values, representing 21.11% and 21.01% of the recommended dietary allowance of 2000 kcal/day, respectively [50]. Regarding mineral content, TV2 showed the highest levels of calcium (7.47%) and zinc (75.89%) per 100 g, based on the recommended dietary allowance of 700 mg/day and 5.6 mg/day, respectively. In contrast, TV3 showed the highest iron content, 32.83% per 100 g, based on the recommended dietary allowance of 7.4 mg/day [51].

3.8. Alkaline Water Retention Capacity (AWRC) of tortilla bread

AWRC is a rapid test used to assess the deterioration, retrogradation, or staling, as well as the freshness, of tortilla bread. AWRC shows an in-

verse correlation with staling and a positive correlation with freshness. A higher AWRC value indicates higher freshness of the bread [52]. Tortilla samples were evaluated after baking (zero time) and after certain storage periods (24, 48, and 72 hours), as illustrated in the Figure 2. The data showed that AWRC values decreased with increasing storage periods in all tortilla samples. AWRC at zero time ranged from (417.12% to 521.75%), after 24 hours (391.54% – 429.86%), after 48 hours (361.17% – 412.42%), and after 72 hours (320.85% – 387.48%). Notably, tortilla bread samples TV1, TV2, and TV3 exhibited higher AWRC values compared to their control samples (TCon1, TCon2, and TCon3) throughout all storage periods. TV1 featured the highest AWRC, making it the freshest sample across all time, followed by TV2, and TV3, consistent with the positive correlation between higher AWRC and higher freshness degree. A higher AWRC is positively related to gelatinized starch, while lower values reflect a greater proportion of retrograded starch, which is characterized by reduced water-binding capacity [25]. The higher AWRC and enhanced degree of freshness observed in tortilla samples (TV1, TV2, and TV3) may be attributed to calcium application during the maize cultivation, which helps retain water and reduce kernel desiccation, thereby improving the water-holding capacity of the obtained tortilla bread. Calcium enhanced the water-holding capacity [53].

4. Conclusion

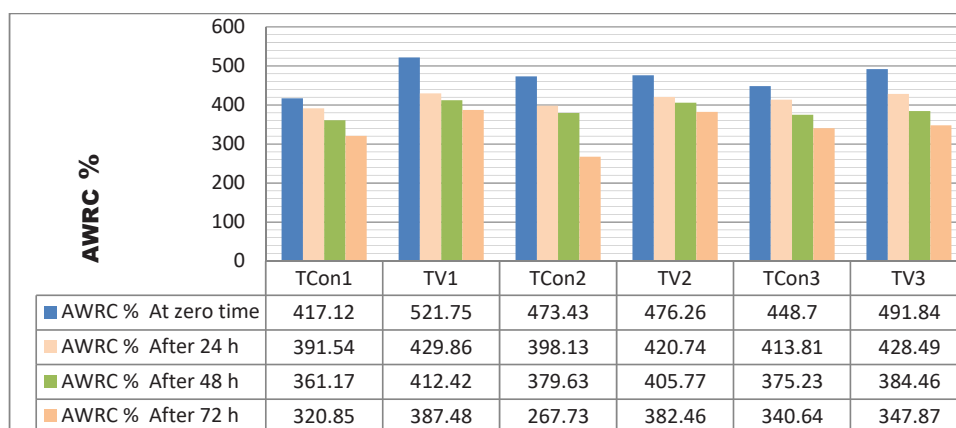
This study demonstrated that drought-tolerant maize cultivars cultivated under drought-exposed conditions and treated with calcium foliar fertilization exhibited enhanced protein, fiber, and mineral contents, as well as improved rheological properties. Consequently, these cultivars produced tortilla bread characterized by superior sensory quality, nutritional value, and storage stability. These findings underscore the potential of drought-tolerant maize to decrease dependence on imports of the food, promote sustainable domestic agricultural development, facilitate profitable agricultural production, and support the consumers with gluten intolerance. Further research is required to explore the effects of calcium fertilization on other maize genotypes in varieties breeding programs aimed at improving maize quality under stress conditions and to assess consumer's acceptance of these food products.

Table 8. Dietary reference intake of tortilla bread / 100 g for children aged (3–10) years

Таблица 8. Рекомендуемая суточная норма потребления тортильи в пересчете на 100 г продукта для детей в возрасте от 3 до 10 лет

DRI	DRI of protein / 100 g	DRI of T.C /100g	DRI of TCV /100g	DRI of Ca/100g	DRI of Zn/100g	DRI of Fe / 100g
TCon1	21.71	64.36	21.11	4.52	59.64	21.75
TV1	24.10	64.97	20.64	5.49	74.46	24.86
TCon2	33.39	63.94	20.52	6.63	62.50	21.75
TV2	34.96	63.71	20.54	7.47	75.89	31.35
TCon3	21.35	67.26	20.42	5.06	61.60	16.08
TV3	24.89	64.49	21.01	7.33	72.85	32.83
DRI**	Based on 28 g/day	Based on 130 g/day	Based on 2000 Kcal/day	Based on 700 mg/day	Based on 5.6 mg/day	Based on 7.4 mg/day

TCon1, TCon2, and TCon3 are tortilla breads as control samples of three cultivars as follows: SCP3444, Sammaz-35, and EVDI, respectively, and TV1, TV2, and TV3 are tortilla breads of three cultivars cultivated under drought-exposed conditions using calcium foliar fertilization as follows: SCP3444, Sammaz-35, and EVDI, respectively.



TCon1, TCon2, and TCon3 are tortilla breads as control samples of three cultivars as follows: SCP3444, Sammaz-35, and EVDI, respectively, and TV1, TV2, and TV3 are tortilla breads of three cultivars cultivated under drought-exposed conditions using calcium foliar fertilization as follows: SCP3444, Sammaz-35, and EVDI, respectively.

Figure 2. Alkaline Water Retention Capacity (AWRC) of tortilla bread

Рисунок 2. Щелочная влагоудерживающая способность тортильи

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Conflict of interest		Конфликт интересов	
The authors declare no conflict of interest.		Авторы заявляют об отсутствии конфликта интересов.	