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Quality characteristics of snacks produced from nixtamalized corn flours of new drought-tolerant yellow corn hybrids

Attia A. Yaseen, Ahmed M. Hussein, Ramadan M. Esmail, Ayman A. Mohammad*

National Research Centre, Cairo, Egypt

* e-mail: aymnmohamed79@yahoo.com

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Abstract:
Introduction. Producing new maize cultivars in areas with limited water resources is the main task of plant breeders. However, there is little information regarding their technological characteristics and industrial potential. Besides, snacks have gained worldwide acceptability and become part of modern food culture, especially among young people and children. Thus, our study aimed to produce corn snacks from new yellow corn hybrids planted under water stress in Delta region, Egypt.
Study objects and methods. We investigated healthy processing techniques and used nixtamalization and baking instead of frying. We also evaluated the chemical composition and starch crystallinity of flour, the rheological properties of dough, as well as color attributes and sensory characteristics of baked snacks.
Results and discussion. Significant differences ($P < 0.05$) were found between all corn genotypes in their fat, protein, ash, crude fiber, and carbohydrate contents. The experimental drought conditions caused higher protein and fat contents compared to normal conditions. X-ray diffraction indicated that nixtamalization decreased starch crystallinity. Also, X-ray and rapid visco analysis showed that Y2 genotype exhibited the highest crystallinity and the lowest pasting properties, while Y3 and Y5 had the lowest crystallinity and the highest pasting properties. Baked snacks made from nixtamalized corn flour of genotypes planted under drought conditions had comparable quality characteristics in terms of color and sensory properties to the control snacks made from SC178 genotype planted under normal conditions.
Conclusion. The new corn hybrids grown in limited water conditions and the developed snacks represent a healthy alternative to corn-based fried snacks.

Keywords: Drought-tolerant plants, nixtamalization, X-ray, snacks, sensory evaluation, corn

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INTRODUCTION

In recent years, snack foods have gained importance and popularity worldwide and become part of modern food culture. However, they have a low nutritional value due to high carbohydrate and fat contents and a low protein content [1]. Moreover, the dependence on convenience snacks has exposed consumers to a higher risk of obesity, cardio-vascular disease, and cancer [2]. Recently, with the revolution in food marketing and the consumer trend towards healthier low sodium, low oil, and low calorie foods, it is necessary to develop new products that offer quality, variety, cost-efficiency, convenience, and nutritive value [3].

The current trend in the food industry is to develop more nutritive snack foods, rather than eliminate snacks from the diet, largely due to their economic value [1]. Snacks has become very popular all over the world, especially among children [4]. Tortilla chips and corn chips are the most popular corn-based snack products. Corn chips are fried products made from corn flour, while tortilla chips are Mexican corn snacks traditionally manufactured from nixtamalized corn grains with or without frying [5]. The resulting snacks, even fried after baking, have a lower oil content, firmer texture, and a stronger alkaline flavor compared to corn chips. They are convenient, ready-to eat, and inexpensive corn products with digestive and dietary principles of vital importance [6].

Nixtamalization is a process that involves alkaline cooking and steeping of corn kernels, which are then washed and ground to produce masa (soft and moist dough). Corn masa is kneaded and molded, and then baked on a hot griddle for tortilla chips [7–8]. Nixtamalization provides nutritional, technological, and safety benefits to corn grains. The nutritional benefits include improved protein quality, increased calcium and B-vitamins availability, and reduced phytic acid and tannins contents [9]. Technologically, nixtamalized grains are more easily ground due to softer pericarp and endosperm, with gelatinized starch and improved aroma. In addition, nixtamalization reduces mycotoxin contents in corn grains [10].

Maize is a vital crop for both human food and livestock feed, and the demand for maize and its products grows day by day due to its versatile uses, including medicine, textile, and biofuel production [11–12]. By 2025, maize will be the most common crop produced all over the world [13]. Water and productive land limitation leads plant breeders to vertical expansion through improving the efficiency of water use and increasing unit area productivity [14–15].

In this regard, maize production programs are continuously trying to increase yield, quality, and stability under water deficit conditions [16]. While grain yield is a commonly investigated parameter, quality and technological parameters have less attention [17]. Therefore, we aimed to investigate the possibility of using nixtamalized corn flours – obtained from the best yellow corn hybrids based on grain yield under drought conditions – in baked corn snacks production.

STUDY OBJECTS AND METHODS

Raw materials. For this study, we used materials planted under normal and water stress (drought) conditions in the Experimental Farm of Agricultural Research Centre (ARC), Delta region, EL-Kalyubia Governorate, Egypt. We selected six of the best yellow maize crosses (Y –Y6) according to their superiority in grain yield under drought conditions in the field experiment (yield and irrigation data published in Esmail *et al.*) [14]. They were obtained from hybridization between the imported CIMMYET parental lines following the half-diallel crossing system. Single cross Giza 178 was used as a chick variety. Chemicals and other ingredients for ready-made snacks production were purchased from the local market.

Chemical composition. Moisture, ash, fiber, protein, and fat contents in corn hybrids were determined by methods recommended by the Association of Official Analytical Chemists [18]. Total carbohydrates were calculated by difference.

Preparation of nixtamalized corn flour. Nixtamalized corn flour was prepared according to the method of Quintanar-Guzman *et al.* with some modification [19]. In particular, corn kernels were boiled in a 1% calcium hydroxide solution (percent by grain weight) for 2 h, soaked in boiled water for 14 h, and washed with excess tap water followed by decantation using a sieve. The washed nixtamalized grains were dried for 8–10 h at 60°C and then cooled to 25°C. The dried grains were milled in an analytical mill (Brabender mill, Junior) to pass a 60 mesh screen (0.0028 in sieve opening), and a minimum of 0.102 ± 0.06 cm of free space between the shaft and the stationary body of the mill. The masa prepared from grains was packed in polyethylene bags and stored in a refrigerator (4°C) until use.

X-ray diffraction. Starch crystallinity was evaluated by X-ray diffraction patterns of the samples using monochromatic CuK radiation on a Philips X-ray diffract meter at 35 kv and 15 mA (Central Lab, National Research Centre, Egypt). Lyophilized samples were placed on the 1 cm^2 surface of a glass slide and equilibrated overnight at * a relafive humidity of 91% and run at 2–32 θ (diffraction angle 2 θ). The spacing was computed according to Bragg's law [20].

Pasting properties of flours. Pasting properties of nixtamalized corn flours were determined using a rapid visco analyzer starch master R&D pack V 3.0 (Newport Scientific Narrabeen, Australia) according to the methods approved by the American Association of Cereal Chemists [21]. The measured parameters were pasting temperature, peak viscosity, trough viscosity, final viscosity, breakdown and setback viscosity.

Preparation of snacks. Snacks were prepared according to Agrahar-Murugkar *et al.* by mixing 100 g NCF and 3 g salt in a planetary mixer for 2 min at a low speed using a flat blade, then adding 15 mL sunflower oil and mixing for another 6 min [2]. After this, we changed the mixer blade to a hook type, added 50 mL water, and mixed the dough for about 2 min at a low speed, followed by a medium speed for 2–4 min until soft, cohesive and pliable dough developed. The prepared dough was covered with wet muslin cloth and left to rest for 5 min at room temperature. Then, we sheeted it manually, cut in a circular shape (1.50 mm thick) and baked at 180°C for 8 min on one side and another 5 min on the other side. The chips were then dried for 1 h at 70°C and cooled to room temperature.

Color quality of processed snacks. The color parameters of snacks were evaluated using a Hunter color meter (Hunter Associates Lab Inc. (Model No: LabScan XE, USA). The instrument was calibrated with a white standard tile of Hunter Lab color standard (LX No. 16379): x = 77.26, y = 81.94 and z = 88.14 (L^* = 92.43, a^* = −0.88, b^* = 0.21). The results were expressed in accordance with the CIELAB system for L^* (L^* = 0 [black], L^* = 100 [white]), a^* ($-a^*$ = greenness, $+a^*$ = redness), and b^* ($-b^*$ = blueness, $+b^*$ = yellowness). In addition, the total color difference (ΔE) between the control snacks (made from SC178 planted under normal irrigation conditions) and those made from corn genotypes planted under drought conditions was calculated as follows:

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{0.5}$$

Along with this, we calculated Hue angle, Chroma, and Browning Index (BI) using the following expression:

$$\text{Chroma} = [(a^*)^2 + (b^*)^2]^{0.5}$$

$$\text{Hue angle} = \tan^{-1}(b^*/a^*)$$

$$\text{Browning Index (BI)} = \frac{[100\,(x - 0.31)]}{0.17}$$

$$\text{Where, } x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)}$$

Sensory evaluation. Snacks were evaluated for their sensory characteristics by 15 trained panelists. The tested characteristics included color, flavor, taste, crispiness, appearance, and overall acceptability [22].

Statistical analysis. The obtained data were statistically analyzed using the SAS Systems for Windows software, version 6.12 TS020 (SAS, Statistical Analysis System, Institute Inc., Cary, NC, 1996). We performed analysis of variance (ANOVA) and the least significant difference (LSD) test ($P < 0.05$) to determine significant differences between the treatment means.

RESULTS AND DISCUSSION

Chemical composition of yellow corn hybrids. The chemical composition of tested corn samples planted under normal irrigation and drought conditions is presented in Table 1. We found significant genotype differences in moisture, protein, fat, fiber, ash, and carbohydrates. The moisture contents of corn genotypes varied in a narrow range from 11.33 to 12.70%. We noticed a slight decrement in moisture among all corn hybrids planted under drought conditions compared to normal conditions. This decrement was insignificant in some genotypes (SC178, Y1, Y2, and Y5) and significant in others (Y3, Y4, and Y6). The protein content, however, varied in a wide range: its highest value (13.28%) was found in Y4 genotype planted under drought conditions and the lowest (9.52%), in Y6 genotype planted under normal conditions. Also, the fat content varied from 4.28 to 5.50% for Y6 and Y2 genotypes planted under normal conditions, respectively.

Generally, we found that the corn genotypes planted under drought conditions had higher protein and fat contents compared to those planted under normal conditions. Each genotype showed higher protein and fat contents under water stress conditions compared to normal conditions. Carbohydrate contents, however, showed a reverse trend. Similar results were reported by Barutcular *et al.* for maize and Rharrabti *et al.* for wheat [12, 23]. Mousavi *et al.* reported that water stress, especially during the flowering stage, affected the photosynthesis process and thus greatly decreased the starch content while increasing protein and fat contents in the grains [24].

The fiber contents of corn genotypes varied from 2.95 to 3.30% for Y2 planted under water stress and SC178 planted under normal conditions, respectively. At the varietal level, there were no significant differences between the fiber contents of Y1, Y2, Y4, and Y5 genotypes under both irrigation conditions. Fiber contents of SC17 and Y6 genotypes showed a significant decrement under drought conditions compared to normal conditions. By contrast, Y3 genotype revealed a significant increment in fiber under drought conditions. Regarding ash, we found that SC178 showed the highest

Table 1 Chemical composition of yellow corn genotypes (% on dry weight basis)

Genotype	Moisture	Protein	Fat	Fiber	Ash	Carbohydrates
			Yellow corn hybrids planted under normal conditions			
SC178	11.82^{BCD}	10.15^{F}	4.39^{F}	3.30^{A}	1.65^{A}	80.51^{AB}
Y1	11.95^{BC}	9.75^{G}	5.20^{B}	3.12^{BC}	1.44^{BC}	80.49^{AB}
Y2	11.09^{E}	10.90^{CD}	5.21^{B}	3.19^{ABC}	1.30^{D}	79.40^{BCD}
Y3	12.22^{AB}	10.65^{DE}	4.80^{D}	2.98^{EF}	1.31^{CD}	80.26^{AB}
Y4	12.70^{A}	10.50^{EF}	4.50^{EF}	3.10^{CDE}	1.26^{DE}	80.64^{AB}
Y5	11.70^{CD}	10.51^{E}	4.30^{F}	3.20^{ABC}	1.32^{CD}	80.67^{AB}
Y6	12.50^{A}	9.52^{G}	4.28^{F}	3.29^{A}	1.19^{DEF}	81.72^{A}
			Yellow corn hybrids planted under drought conditions			
SC178	11.50^{CDE}	11.80^{B}	4.90^{CD}	3.10^{CDE}	1.12^{F}	79.08^{BCD}
Y1	11.56^{CDE}	10.78^{CDE}	5.10^{BC}	3.10^{CDE}	1.49^{B}	79.53^{BCD}
Y2	11.51^{CDE}	11.69^{B}	5.50^{A}	2.95^{F}	1.19^{DEF}	78.67^{CD}
Y3	11.40^{DE}	13.01^{A}	4.50^{EF}	3.17^{ABC}	1.25^{DE}	78.17^{CD}
Y4	11.33^{DE}	13.28^{A}	4.70^{DE}	3.20^{ABC}	1.22^{DEF}	77.60^{D}
Y5	11.65^{CD}	11.05^{C}	4.79^{E}	3.25^{AB}	1.30^{D}	79.61^{BC}
Y6	11.59^{CDE}	10.89^{CD}	4.80^{E}	3.03^{DEF}	1.15^{EF}	80.13^{ABC}
LSD	0.5103	0.3591	0.2536	0.1345	0.1397	1.9701

SC178 = Single Cross Giza 178, Y1–Y6 = new yellow corn hybrids
Means with the same letters in the same column are not significantly different

value (1.65%) under normal irrigation and the lowest value (1.12%) under drought conditions. However, there were no significant differences between the ash contents of the six new genotypes under both irrigation conditions.

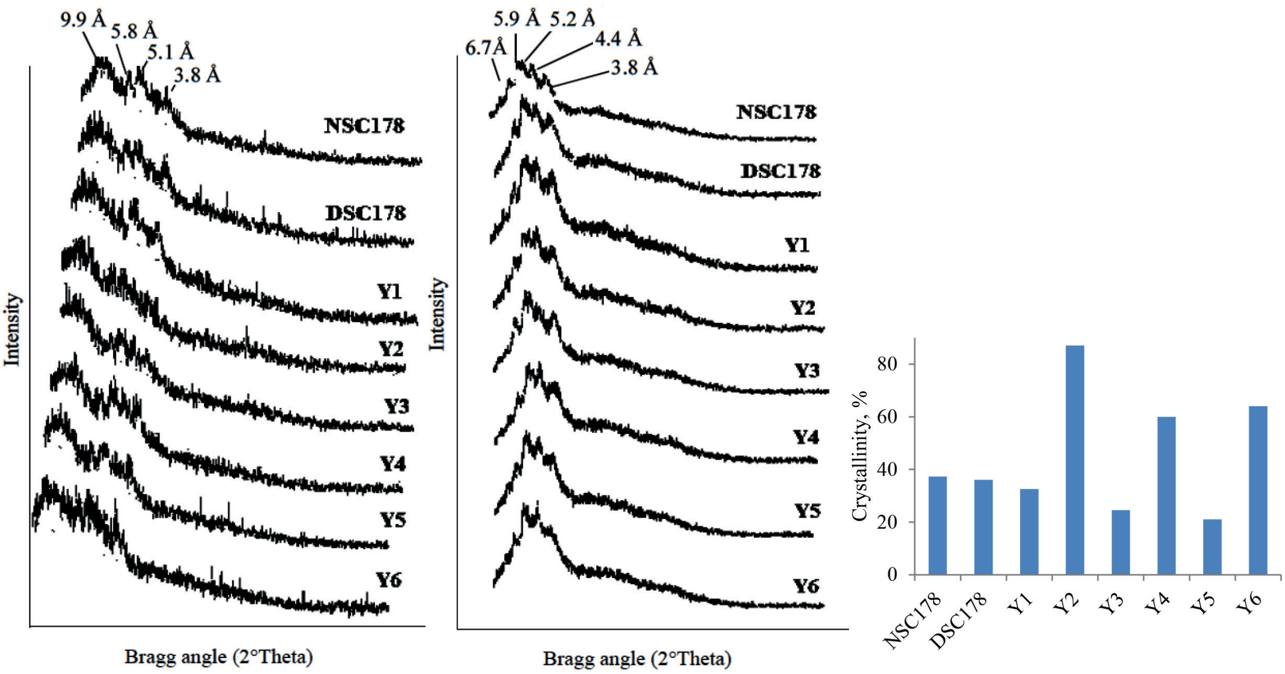
The high protein and fat yielding genotypes and the comparable fiber and ash contents under drought conditions may be due to the drought tolerance of the new hybrids. The chemical composition of yellow maize (on a dry weight basis) was previously reported by Watson as 71.7% starch, 9.5% protein, 4.3% fat, and 1.4% ash [25]. Compared to these data, all the corn genotypes in our study had high protein and fat contents. Similar values for these macronutrients were also found among 1245 corn samples from different locations all over the world [26]. Also, the reported values for moisture and fat contents of yellow corn are close to those reported by Yaseen *et al.* and Hussein *et al.*, being 12.50 and 5.15%, respectively [27, 28]. However, they reported lower values for crude protein (7.88%), ash (0.5%), crude fiber (2.5%), and total carbohydrates (76.0%).

Starch crystallinity of yellow corn genotypes. The X-ray diffraction pattern diagrams for raw and nixtamalized corn samples are shown in Fig. 1a and B, respectively), and the respective crystallinities are illustrated in Fig. 1c. All raw corn genotypes planted under normal and drought conditions showed A-type diffraction peaks around 9.9, 5.8, 5.1 and 3.8 Å at 8.8°, 15.0°, 17.4° and 22.9° (at 2θ), respectively. There were no clear differences between the diffractograms of yellow corn genotypes.

Similar results were previously reported in [29–32]. They stated that X-ray diffractions of native cereal starches showed pure “A” type peaks. In addition, Abd-Allah *et al.* mentioned that the calculated “d” spacing of yellow corn starch ranged between 5.4004 and 3.4767 Å [29]. Also, they assumed that symmetric X-ray diffraction patterns of the tested samples could be due to the fact that cereal starch is a homogeneous material mainly composed of amylose and amylopectin. On the other hand, the specified diffracting angle (at 2θ) for each peak in each starch type could be explained by the molecular weight and the amylose/amylopectin ratio variations.

As we can see in Fig. 1b, a diffraction peak at about 4.4 Å was developed in the nixtamalized samples. It is also clear that the specified peaks in the NCF diffractograms were characterized by decreased intensity and broad background compared to those in the raw samples (Fig. 1a). The peak at 4.4 is the first indication of a V-type amylose-lipid complex pattern [33].

Arambula *et al.* revealed that an amylose–lipid complex developed as a result of starch gelatinization during extrusion or nixtamalization of corn flour [31]. Besides, Mondragon *et al.* mentioned that amylose–lipid complexes might develop during alkali steeping [34]. Finally, Agrahar-Murugkar *et al.* noted that the location of this peak was slightly displaced from the strong 4.4 Å



(a) (b) (c)

Figure 1 X-ray diffraction diagrams for raw corn samples (a) and nixtamalized corn samples (b), and crystallinity values for raw corn samples (c). NSC178 = Single Cross Giza 178 planted under normal conditions, DSC178 = Single Cross Giza 178 planted under drought conditions, Y1–Y6 = new yellow corn hybrids planted under drought conditions to around 4.5–4.7 Å in the X-ray pattern of fried tortilla chips [2].

Beside the transition from pure "A" pattern in raw corn flour to "A + V" pattern in NCF, the decreased peak intensity and its broad background indicated the transition from the semi-crystalline phase to the amorphous phase resulting in a partial disruption of the crystalline starch structure [31, 34]. As we can see in Fig. 1c, Y2 genotype had the highest crystallinity value (87.11%), followed by Y6 and Y4 genotypes (64 and 60%, respectively). Y3 genotype had a lower crystallinity value (24.58%), with the lowest recorded for Y5 (21%). In general, starch crystallinity in corn flours may be affected by mechanical (milling process) and amylolytic activity, as it decreases with damage caused to starch granules [32, 35].

Pasting properties of hybrid nixtamalized corn flour. The pasting properties of NCF dough were rheologically evaluated by a rapid visco analyzer (Table 2). The results showed wide variations in peak viscosity, trough value, breakdown, final, and setback viscosity of yellow corn hybrids planted under drought conditions. However, all corn hybrids showed the same peak time. For instance, the peak and final viscosity values ranged from 151 cp to 660 cp and from 250 cp to 1186 cp for Y2 and Y3 genotypes, respectively. The trough value, breakdown and final viscosity ranged from 128 cp to 541 cp, from 23 cp to 119 cp, and from 122 cp to 645 cp for the same genotypes, respectively. All parameters were greater for Y3 genotype, while Y2 genotype had lower parameters.

Pasting properties are measurements of starch behavior (gelatinization and retrogradation) during processing [36]. These properties could be affected by the molecular structure of amylopectin (branch chain length and distribution) [37] and the granule size [38]. Amylopectin contributes to swelling and pasting of starch during heating. Amylose contributes to starch retrogradation during the cooling stage through its aggregation by hydrogen bonds [39].

It was indicated that the presence of lipids restricts the swelling of starch granules and amylose leaching, resulting in reduced viscosity of the corn flour paste during gelatinization, whereas amylose and lipids inhibit the swelling [40, 41]. In our study, the lower viscosity values of Y2 hybrid could be due to its high fat content (Table 1) and a higher crystallinity degree (Fig. 1c). On the other hand, Sefa-Dedeh *et al.* reported a drastic reduction in the pasting properties of NCF compared to raw flour [9]. They attributed the reduction in viscosity, especially during the cooling stage, to the saturation of hydroxyl groups on the starch molecules with calcium ions (Ca_2^{+}). The resulting $Ca(OH)^{+}$ ions prevent any further association of the starch molecules in the cooked paste viscosity.

Color attributes of corn snacks. The color of nixtamalized corn flour-based products is an important quality parameter which directly influences the consumer's acceptability of the product. Table 3 and Fig. 2 show the color quality of snacks manufactured from NCF of SC178 genotype planted under normal and water stress conditions, as well as the new hybrids (Y1–Y6) planted under water stress conditions. We found a wide range of significant differences for all color parameters of the snacks: 61.58 − 69.91, 3.35 − 9.17 and 25.02–32.12 for lightness (L*), redness (a*) and yellowness (b*), respectively.

Noteworthily, the snacks produced from SC178 genotype planted under normal irrigation conditions showed the lowest L* and the highest a* and b* values. The highest L* was recorded for snacks produced from Y1, while the lowest a* and b* values were recorded for snacks produced from Y4 genotype. The total color differences (ΔE), chroma (C*), hue angle (H*) and browning index (B.I.) varied between 8.23 − 11.96, 25.24–33.40, 74.05–83.32 and 47.36–82.16, respectively.

The snacks produced from corn hybrids planted under drought conditions tended to have higher L* and H* values and lower a*, b*, C* and BI values, compared to those produced from SC178 planted under normal conditions. Similar previous studies stated that the color of NCF ranged from white to dark yellow, depending on the alkali concentration, processing conditions, and corn type [2, 42, 43]. In addition, Sefa-Dedeh *et al.* stated that the yellowish color in NCF-based products, even when produced from white corn, was closely related to the

Table 2 Pasting properties of nixtamalized corn flour

Sample	Peak Time, min	Peak Viscosity, c.p.	Trough, c.p.	Breakdown, c.p.	Final Viscosity, c.p.	Setback, c.p.
NSC178	7.0	535	430	93	932	502
DSC178	7.0	569	471	98	952	481
Y1	7.0	430	354	76	784	430
Y2	6.9	151	128	23	250	122
Y3	7.0	660	541	119	1186	645
Y4	7.0	214	172	42	344	172
Y5	7.0	577	482	95	980	498
Y6	7.0	177	145	32	287	142

NSC178 = Single Cross Giza 178 planted under normal conditions, DSC178 = Single Cross Giza 178 planted under drought conditions, Y1–Y6 = new yellow corn hybrids planted under drought conditions

Table 3 Color attributes of snacks from drought-tolerant corn genotypes

Samples	Lightness (L*)	Redness (*a**)	Yellowness (*b**)	Total color differences (ΔE)	Chroma (*C**)	Hue angle (*H**)	Browning index (B.I.)
NSC178	61.58^{D}	9.17^{A}	32.12^{A}	0.00^{E}	33.40^{A}	74.05^{D}	82.16^{A}
DSC178	69.53^{AB}	3.33^{G}	28.45^{D}	10.53^{B}	28.64^{D}	83.32^{A}	54.75^{D}
Y1	69.91^{A}	3.82^{E}	29.53^{C}	10.23^{B}	29.78^{C}	82.63^{A}	57.42^{C}
Y2	69.03^{AB}	4.99^{B}	26.24^{F}	10.37^{B}	26.71^{F}	79.24^{C}	52.09^{E}
Y3	66.93^{C}	3.55^{F}	27.26^{E}	9.16^{C}	27.49^{E}	82.58^{A}	54.85^{D}
Y4	69.25^{AB}	3.35^{G}	25.02^{G}	11.96^{A}	25.24^{G}	82.38^{A}	47.36^{F}
Y5	68.58^{B}	4.88^{C}	30.06^{B}	8.46^{D}	30.45^{B}	80.78^{B}	61.34^{B}
Y6	66.37^{C}	4.49^{D}	27.34^{E}	8.23^{D}	27.71^{E}	80.68^{B}	56.74^{C}
LSD	1.1735	0.0859	0.4883	0.6242	0.4982	1.3986	1.0263

NSC178 = Single Cross Giza 178 planted under normal conditions, DSC178 = Single Cross Giza 178 planted under drought conditions, Y1–Y6 = new yellow corn hybrids planted under drought conditions

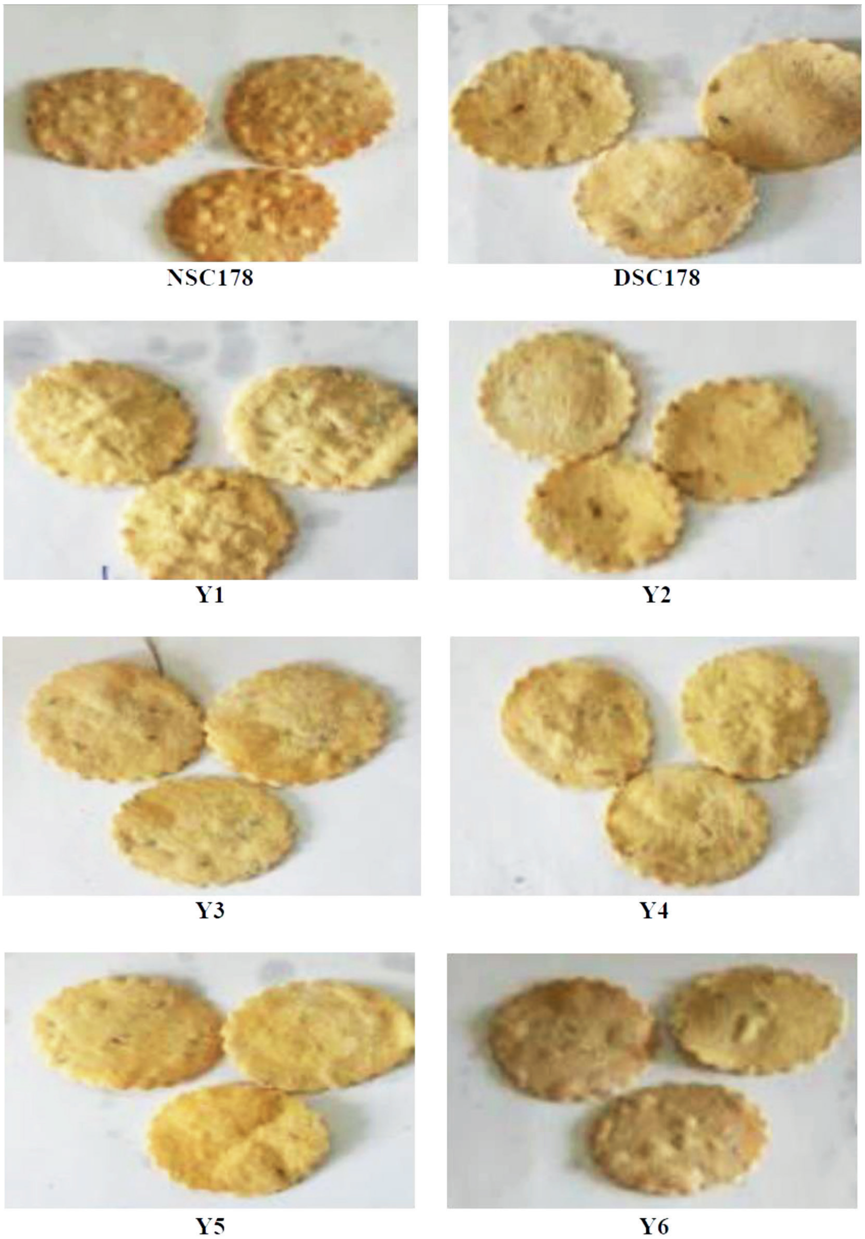


Figure 2 Snacks processed from drought-tolerant corn genotypes. NSC178 = Single Cross Giza 178 planted under normal conditions, DSC178 = Single Cross Giza 178 planted under drought conditions, Y1–Y6 = new yellow corn hybrids planted under drought conditions

Table 4 Sensory characteristics of snacks from drought-tolerant corn genotypes

Genotypes	Color (10)	Crispiness (10)	Odor (10)	Taste (10)	Appearance (10)	Overall acceptability (10)
NSC178	9.1^{A}	9.1^{A}	9.4^{A}	9.0^{A}	8.9^{A}	8.8^{A}
DSC178	8.3^{BCD}	8.5^{BC}	8.6^{B}	8.3^{BC}	8.6^{AB}	8.4^{AB}
Y1	6.4^{E}	8.1^{CD}	8.4^{B}	7.9^{CD}	8.2^{BC}	8.1^{BC}
Y2	6.0^{E}	7.7^{D}	8.1^{B}	7.5^{D}	7.8^{C}	7.6^{C}
Y3	8.6^{ABC}	8.0^{CD}	8.3^{B}	7.8^{CD}	8.1^{BC}	7.9^{BC}
Y4	8.0^{D}	8.2^{CD}	8.5^{B}	8.0^{CD}	8.3^{BC}	8.1^{BC}
Y5	8.8^{AB}	8.9^{AB}	9.2^{A}	8.7^{AB}	9.0^{A}	8.9^{A}
Y6	8.2^{CD}	7.9^{D}	8.2^{B}	7.7^{D}	8.0^{C}	7.8^{C}
LSD	0.552	0.576	0.596	0.564	0.579	0.558

NSC178 = Single Cross Giza 178 planted under normal conditions, DSC178 = Single Cross Giza 178 planted under drought conditions, Y1–Y6 = new yellow corn hybrids planted under drought conditions

lime concentration [9]. This observation could be due to the varietal performance of yellow corn hybrids (yellow pigments content) under drought conditions.

Browning index (BI) is the most important color attribute in baked products because it affects their final quality [44]. With respect to the yellow pigments content, browning coloration could be due to both enzymatic and non-enzymatic reactions. During nixtamalization, once cell walls and cellular membranes lose their integrity, enzymatic oxidation of phenolic compounds rapidly takes place by polyphenols oxidase [45]. However, the non-enzymatic Maillard reaction takes place between reducing sugars and proteins during the baking process.

Sensory evaluation of corn snacks. The mean scores of sensory characteristics (Table 4) showed significant differences ($P \leq 0.05$) between the genotypes for color, crispiness, odor, taste, appearance, and overall acceptability. The snacks produced from SC178 planted under normal conditions and Y5 planted under drought conditions were rated highest in all sensory attributes, while those produced from Y2 were rated lowest. As we said above, color is a very important quality parameter of baked products that reflects raw material formulation and processing.

The brown-yellow color measured by the Hunter instrument (Table 3) for the snack samples manufactured from SC178 and Y5 NCF confirmed the results of sensory analysis. The favorable taste and aroma of these samples could be due to the Millard reaction that takes place during baking. In a similar work by Agrahar-Murugkar *et al.*, nixtamalization improved the sensory properties of chips [2]. Further, in a study to identify the market demand for corn-based snacks, Menis-Henrique *et al.* found a need for snacks with a lower fat content and a better nutritional value [46]. Therefore, we can conclude that nixtamalized corn flour is organoleptically superior and this technology could be used on a commercial scale.

CONCLUSION

We found that Y3 and Y5 genotypes grown under water stress conditions provide corn grains with superior quality that can be used in snack production. Also, we can conclude that baked snacks made from nixtamalized corn flour are a healthy alternative to fried snacks. Finally, these findings could contribute to achieve both food and nutritional security, especially in water scarce areas.

CONTRIBUTION

The authors were equally involved in designing the research plan. Prof. Ramadan Esmail was involved in the production and cultivation of new yellow corn hybrids. Ahmed Hussein and Ayman Mohammad took part in the production of NCF, as well as in the manufacture and evaluation of snacks. Attia Yaseen and Ayman Mohammad were involved in writing the manuscript, and Ayman Mohammad checked it for plagiarism.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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ORCID IDs

Attia A. Yaseen https://orcid.org/0000-0002-4083-9199
Ahmed M. Hussein https://orcid.org/0000-0001-6297-3439
Ramadan M. Esmail https://orcid.org/0000-0002-4417-1333
Ayman A. Mohammad https://orcid.org/0000-0001-6114-4217