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Color characteristics of white salted, alkaline, and egg noodles prepared from *Triticum aestivum* L. and a soft kernel durum *T. turgidum* ssp. *durum*

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Abstract

Background and objectives: Durum wheat (*Triticum turgidum* L. ssp. *durum*) may have advantages over bread wheat in making various styles of noodles due to low polyphenol oxidase (PPO) and high yellow pigment. However, the very hard kernel texture of durum wheat may pose a hindrance to its expanded utilization. The development of soft kernel durum wheat prompted this research into comparing the color of white salted, alkaline, and egg noodle sheets over time and three levels of hydration for one durum and 10 hexaploid wheat varieties.

Findings: All noodle sheets darkened over time and "varieties" was a major source of variation. PPO activity was a poor predictor of noodle sheet brightness (L^*) at 48 hr for all three styles of noodle. The soft durum variety "Soft Svevo" exhibited about average brightness but tended to have low discoloration (ΔL^*) over time. The range in the green-red axis, a^*, was small, and all noodle sheets exhibited a small positive increase with most values near the neutral gray value. All noodle sheets were yellow, with Soft Svevo being markedly more yellow in all three formulations. The alkaline pH increased average yellowness by three units overall, but in Soft Svevo, not at all. In some varieties, a decrease in yellow color occurred from 6 to 48 hr.

Conclusions: The low PPO activity of Soft Svevo did not predict an advantage in white salted, alkaline, and egg noodle sheet brightness over the "best" hexaploid wheat varieties. The reason was not resolved but may be related to marked differences in protein content of the flours.

Significance and novelty: Soft kernel durum wheat exhibited some advantages over hexaploid wheat, particularly in low discoloration (ΔL^*) and high yellow color. In no way was soft durum found to be inferior to hexaploid wheat.

KEYWORDS
alkaline noodle, egg noodle, noodle color, soft kernel durum, white salted noodle

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1 | INTRODUCTION

Wheat (*Triticum* spp. L.) noodles begin as relatively low moisture doughs that are then sheeted, cut into strands, and subsequently processed in a number of different ways (Hou, 2010; Kruger, Matsuo, & Dick, 1996; Morris & Rose, 1996). Here, delineation is made between "noodles"—processed by sheeting, and "pasta"—processed by extrusion. Although pasta is first and foremost made from durum wheat (*T. turgidum* subsp. *durum* [Desf. (Husn.)]), in some parts of the world pasta is made from "bread wheat" (*T. aestivum*) or blends of durum and bread wheat (Martinez, Ribotta, Leon, & Anon, 2007; Murray, Kiszonas, & Morris, 2017b). On the contrary, durum wheat may be used alone or in blends to make noodles of various shapes and styles (Alamprese, Casiraghi, Primavesi, Rossi, & Hidalgo, 2005; Khouryieh, Herald, & Aramouni, 2006).

A simple classification of noodles involves their formulation: "white salted" (also referred to as "udon" in Japan), "alkaline," and "egg" noodles. White salted noodles contain principally flour, water, and NaCl; alkaline noodles, various combinations of sodium and potassium carbonate salts (occasionally sodium hydroxide); and egg noodles, chicken (*Gallus gallus domesticus*) eggs added as liquid or dried (Code of Federal Regulations §139.155; Khouryieh et al., 2006; DPR 2001 cited in Alamprese et al., 2005).

Regardless of the type or classification of noodles, color is a primary quality criterion (Miskelly, 1984; Morris, 2018). Color is conveniently expressed in the C.I.E. triaxial color space, denoted by L^*, "brightness" (black to white); a^*, green to red; and b^* blue to yellow (Wyszecki & Stiles, 2000). Changes over time, especially for darkening or loss of brightness, are denoted by adding the Greek letter Δ (ΔL^*).

There is a tremendous range of color of wheat noodles. Most of the variation in color can be attributed to formula (e.g., presence/absence of alkaline salts or eggs) and wheat variety ("genotype") (Martin et al., 2005; Morris, 2018; Moss, 1971). For white salted noodles, the natural color of the flour is present when noodles are first made (Miskelly, 1984). For alkaline noodles, the high pH produces a variable amount of yellowness due to the flavones apigenin–glycosides, which are colorless at neutral pH, but are detached from starch and turn yellow at high pH (Asenstorfer, Wang, & Mares, 2006; Wijaya & Mares, 2012). At last, in egg noodles, the eggs impart a yellow color due to pigments in the yolk.

Regarding the effects of variety, two primary factors are at play and both are largely under genetic control. The first is the inherent pigmentation of the wheat, especially the bran and endosperm, and the second is darkening reactions associated with polyphenol oxidase (PPO) (Demeke et al., 2001; Miskelly, 1984; Morris, 2018). Bran may be "red" or "white"—essentially pigmented or not, and endosperm may have variable levels of yellow pigment, primarily lutein (Hung & Hatcher, 2011; Seib, Liang, Guan, Liang, & Yang, 2000). Durum wheat varieties are notable for having white bran, high levels of yellow pigments, and low levels of PPO (Anderson & Morris, 2001; Bernier & Howes, 1994; Lamkin, Miller, Nelson, Traylor, & Lee, 1981; Mahoney & Ramsay, 1992). Bread wheats may have white or red bran, typically low levels of yellow pigments, and variable levels of PPO (Baik, Czuchajowska, & Pomeranz, 1994, 1995; Bernier & Howes, 1994; Morris, 2018; Seib et al., 2000).

Of secondary importance to noodle color are kernel properties such as protein content and kernel hardness. Protein in general has a negative correlation with noodle brightness (Baik et al., 1995; Miskelly, 1984; Miskelly & Moss, 1985; Morris, 2018; Moss, 1971). Kernel hardness, although not having a direct effect on color, does influence flour particle size and starch damage, which in turn affect optimum water absorption, processing, and color (He, Yang, Zhang, Quail, & Peña, 2004; Morris, 2018). In general, studies have shown that smaller particle size was beneficial for white salted and alkaline noodles, but higher levels of damaged starch reduced quality (Fu, Assefaw, Sarkar, & Carson, 2006; Hatcher, Anderson, Desjardins, Edwards, & Dexter, 2002; Hatcher, Dexter, & Fu, 2009; Hatcher, Edwards, & Dexter, 2008; Oh, Seib, Ward, & Deyoe, 1985). Flour refinement was the primary factor influencing noodle color and was related to particle size and starch damage. Higher levels of dough water absorption contribute to greater discoloration (Baik et al., 1995; Hatcher, Dexter, & Fu, 2008; Hatcher, Kruger, & Anderson, 1999; Hatcher et al., 2002; Li, Ma, Zhu, Guo, & Zhou, 2016; Morris, 2018; Morris, Jeffers, & Engle, 2000; Oh, Seib, & Chung, 1985; Oh, Seib, Ward, et al., 1985; Park & Baik, 2002; Solah et al., 2007; Zhang et al., 2007).

In the recent past, there has been interest in using durum wheat for noodles in eastern Asia (Fu et al., 2006; Hatcher, Dexter, Anderson, Bellido, & Fu, 2009; Hatcher, Dexter, Bellido, Clarke, & Anderson, 2009; Hatcher, Dexter, et al., 2008; Hung & Hatcher, 2011). Durum wheat has the potential advantages of low PPO and hence low rates of discoloration (Anderson, Fuerst, Hurkman, Vensel, & Morris, 2006; Anderson & Morris, 2001; Bernier & Howes, 1994; Feillet, Autran, & Icard-Verniere, 2000; Fuerst, Anderson, & Morris, 2006a,b; Lamkin et al., 1981; Massa, Beecher, & Morris, 2007; Taranto et al., 2017), and high levels of yellow pigments, which are especially desirable in alkaline noodles (Fu et al., 2006; Hatcher, Dexter, et al., 2008; Hatcher, Dexter, Anderson, et al., 2009; Hatcher, Dexter, Bellido, et al., 2009; Hung & Hatcher, 2011). A disadvantage of durum wheat may lie in its very hard kernel texture. Durum milling is markedly different from soft and hard hexaploid wheat milling (Boehm, Ibba, Kiszonas, & Morris, 2017; Fabriani & Lintas, 1988; Kruger et al., 1996; Morris et al., 2015; Murray, Kiszonas, Wilson, & Morris, 2016; Posner & Hibbs, 1997) and aims to produce the highest yield of semolina. The very hard kernel texture is due to the absence of the puroindoline genes which reside in hexaploid wheat on chromosome 5D (Bhave & Morris, 2008; Boehm, Zhang, Cai, & Morris, 2017; Morris, 2002). Durum semolina and flour have higher water absorption and higher levels of damaged starch than hexaploid wheat flours, especially those from soft wheats (Murray et al., 2016). Fu et al. (2006) found that whereas durum semolina was not suitable for making alkaline noodles, reducing flour particle size largely alleviated the disadvantages of semolina. The caveat was that reducing semolina particle size could result in excessive levels of starch damage.

Whereas durum wheat has very hard kernels, *T. aestivum* may be classified as "soft" or "hard." This classification is based on the alleles of the puroindoline genes *Pina* and *Pinb* located at the *Hardness* locus. The very hard kernel texture of durum wheat was altered recently by the effective translocation of the *Hardness* locus from soft hexaploid wheat (Boehm, Zhang, et al., 2017; Morris, Simeone, King, & Lafiandra, 2011). Morris et al. (2011) back-crossed the trait into the commercial durum cultivar "Svevo." The resultant "Soft Svevo" variety had kernel texture in the range typical of soft wheats. Further, flour particle size, break flour yield, starch damage, and dough water absorption were similar to soft wheat flours (Boehm, Ibba, Kiszonas, & Morris, 2017; Boehm, Ibba, et al., 2017; Morris et al., 2015; Murray, Kiszonas, & Morris, 2017a; Murray et al., 2016).

As a consequence, the development of soft kernel durum wheats may have the potential (due to their soft kernel, low levels of PPO, and high levels of yellow pigment) to produce novel noodle products with outstanding color and color stability. This report evaluates the noodle color performance of Soft Svevo compared to a range of soft white, a hard red spring, and hard red winter wheat varieties, all milled on a pilot-scale Miag Multomat flour mill into "straight-grade" flours.

2 | MATERIAL AND METHODS

2.1 | Grain samples and milling

The varieties included were as follows: Alturas, Diva, Louise, Puma (formerly WA8134), Stephens, WA8124, WB-456, and Xerpha soft white, Farnum, and Glee (formerly WA8074) hard red winter and spring, respectively, and Soft Svevo durum. All hexaploid varieties were included in the Pacific Northwest Wheat Quality Council, an annual industry collaborative evaluation of new and existing wheat varieties using large (>100 kg) samples. Each sample was cleaned and tempered overnight. The soft wheats were tempered to 14% moisture content (fresh weight basis, fwb), and the hard wheats were tempered to 16% moisture content. All samples received an additional 0.5% temper immediately before being milled on a pilot-scale Miag Multomat (Bühler Inc., Minneapolis, MN, USA). These flour samples were used to make white salted, alkaline, and egg noodle sheets and are referred to by variety name.

2.2 | Analytical

Grain samples were evaluated for grain hardness using the SKCS 4100 single kernel characterization system (Perten Instruments, Springfield, IL, USA). Flour protein content ($N \times 5.7$) was determined by the Dumas combustion method (Approved Method 46-30, AACC International, 2010) (model FP-428; Leco Corp., St. Joseph, MI, USA). Flour ash was determined using a Leco TGA-601 Thermogravimetric Analyzer. Both protein and ash were expressed on a 14% flour moisture basis. Flour samples were divided into two replications for each treatment.

Polyphenol oxidase (PPO) in flour was measured for each replication following a modification of Anderson and Morris (2001) using 100 mg flour added to 2-ml-deep wells in a 96-well plate. Flour samples were incubated with 0.5 ml of 5 mM L-DOPA (3, 4-dihydroxy-L-phenylalanine) substrate in 50 mM MOPS ([N-morpholino] propane sulfonic acid) buffer at pH 6.5. The plate was shaken for 7 min on a Beadbeater (BioSpec, Bartlesville, OK, USA) and then left to set on a counter for 10 min at ambient temperature (~21°C). Samples were centrifuged at 3,500 *g* for 5 min. Solutions (200 μl) were transferred to a new 96-well plate. Change in absorbance was compared to a substrate-only control. Change in absorbance was recorded at 475 nm using a SpectraMax Plus^{384} spectrophotometer (Molecular Devices, Sunnyvale, CA, USA).

2.3 | Color measurement

Raw (uncooked) noodle sheet color was measured with a chromometer (model 310, Minolta Camera Co., Ltd., Osaka, Japan) with a 50 mm (diameter) measuring tube, using a white tile background as previously described (Morris et al., 2000). L^*, a^*, and b^* values denote brightness (black-white), green-red, and blue-yellow scales, respectively. Color readings were made at 0, 2, 4, 6, 24, and 48 hr, with three measurements per noodle sheet, each at a different location on the same side of the surface of the noodle sheet. Noodle sheets were stored in plastic bags at ~21°C between color readings. Changes in brightness (darkening) (ΔL^*) were calculated by subtracting readings at 48 hr from zero-time readings. There were two replicate noodle sheets for each treatment.

2.4 | Preparation of white salted noodles

White salted noodle sheets were prepared from 100 g of flour (14% moisture basis) by adding 2% (w/v) sodium chloride solution at the absorption rates of 30%, 32%, and 34% (fwb). The dough was mixed in a Finney Special mixer 100 g Micro Dough pin mixer, head speed 102 rev/min (National Manufacturing Co., TMCO, Inc., Lincoln, NE, USA) for 1 min. Flour adhering to the inside of the mixing bowl and pins was brushed down and added back to the dough mass, followed by an additional 3 min of mixing. The crumbly dough was pressed by hand into a cohesive rectangular block and passed through a laboratory noodle machine (Ohtake Noodle Machine Manufacturing Co. Ltd., Tokyo, Japan) with an initial gap of 4.0 mm. The sheet was "book folded" and sheeted at a 4-mm gap for a total of three times. The irregular edges of the dough sheet were then trimmed off (~6 mm off each edge of the sheet). The sheet was placed into a plastic bag and rested 1 hr. Then, the noodle sheet was progressively reduced by sheeting at 3.1-, 2.3-, 1.7-, and 1.5-mm roll gap without folding. Final thickness of the noodle sheet was 1.5 ± 0.1 mm. The last roll gap was adjusted to accommodate the sheeting characteristics of the particular dough to achieve the desired final thickness. Final thickness was measured by a micrometer dial thickness gauge (Peacock Dial Thickness Gauge G, 0.01–10 mm, Ozaki Mfg. Co., Ltd., Ozaki, Japan). A 15 cm length of noodle sheet was cut transversely from the center of the sheet and used for color analysis. Two replicate analyses of each variety–hydration combination were performed.

2.5 | Preparation of alkaline and egg noodles

Alkaline noodle sheets were made from 100 g of flour (14% moisture basis) by adding a mixture of 0.5% (w/v) sodium carbonate and 2% sodium chloride solution (fwb) at the absorption rates of 30%, 32%, and 34% (fwb). The process of making alkaline noodle sheets was the same as that for white salted noodles.

Egg noodle sheets were made from 100 g of flour (14% moisture basis) by adding fresh hen (*G. gallus domesticus*) eggs at the absorption rate of 38%, 40%, and 42% (fwb). Eggs were prepared by cracking fresh local (supermarket) eggs and stirring egg white and yolk to form a homogeneous mixture. The process of making egg noodle sheets was the same as that for white salted noodles.

2.6 | Statistical analyses

The data were analyzed by SAS software (SAS Institute, Cary, NC, USA). The three repeated color measures were averaged to represent the color of the particular sheet. ANOVA was carried out using the two-grain replicates.

For each type of noodle, the lowest and highest hydration levels are presented in the figures for L^* and b^*. The medium hydration levels (32% for white salted and alkaline, and 40% for egg) are presented in Supporting Information Figures S1–S6. For a^*, hydration levels were averaged for presentation.

3 | RESULTS

3.1 | Grain and flour measurements

As shown in Table 1, nine varieties had a soft kernel texture with SKCS ≤ 41. Soft Svevo, the soft durum, had a particularly soft kernel texture with an SKCS value of 18. The two hard red wheat varieties, Farnum and Glee, had SKCS values of 73.8 and 67.5, respectively. Protein content of the grain lots varied considerably, from 8.8 to 15.0%. As a consequence, flour protein also varied considerably, from 7.1 to 13.6%. Soft Svevo had the highest protein and the highest flour ash (0.59%), whereas the hexaploid wheat flours ranged from 0.34 to 0.47% ash. The L-DOPA PPO analysis showed that Soft Svevo had the lowest PPO activity and Xerpha the highest.

3.2 | White salted noodles

The whole models for L^*, a^*, and b^* were significant with large F-values and p-values <0.0001 (Supporting Information Table S1). All main effects of the model, variety, hydration level, and time had large, significant F-values. Time, in particular, had the largest F-values of 4,899, 1,858, and 841, L^*, a^*, and b^*, respectively. The two-way interactions were variably significant and will be discussed individually. The three-way interactions were considered of little importance.

Noodle brightness is arguably the most critical color parameter for white salted noodles and was assessed by L^*. Differences in L^* existed among varieties, hydration levels, and times. There were also moderate interactions between all the main effects. Although "time" was by far the largest source of variation, it should be kept in mind that in the context of noodle storage and the aims of the present study, individual noodle sheets were compared at the same time point. In this regard, the longest storage time, 48 hr, was considered the most informative as it provided the greatest amount of time for potential discoloration. Nevertheless, the large "time" component highlighted both the inherent differences in brightness, but also the prominent role that darkening plays in noodle quality.

Averaged across hydration levels, Xerpha, had the brightest noodle sheets at both zero and 48 hr (L^* 90.8 and 84.5, respectively), whereas Glee had the darkest noodle sheets at both time points (L^* 83.9 and 67.3) (Figure 1, Supporting Information Figure S1). Soft Svevo fell near the median with L^* values of 86.0 and 78.1, 0 and 48 hr, respectively. As expected, brightness of all varieties

TABLE 1 Grain and flour characteristics of the wheat varietal grain lots used to make white salted, alkaline, and egg noodles

Variety	Class[a]	Test weight (kg/hl)	SKCS hardness (HI)	Grain protein content (%)	Flour protein content (%)	Flour ash (%)	L-DOPA (A_{475})
Soft Svevo	durum	–	18.0	15.0	13.6	0.59	0.179
Xerpha	SWW	81.6	40.7	9.2	7.6	0.49	1.620
Stephens	SWW	80.6	34.7	9.6	8.3	0.38	0.817
WB456	SWW	82.1	37.8	11.3	9.5	0.47	1.276
Puma	SWW	79.9	37.0	9.4	8.0	0.39	0.768
WA8124	SWS	81.9	26.5	8.8	7.1	0.34	1.161
Alturas	SWS	80.2	28.9	11.7	9.9	0.43	0.483
Louise	SWS	80.6	22.7	8.8	7.2	0.38	1.176
Diva	SWS	84.0	22.8	10.2	8.6	0.40	0.935
Farnum	HRW	81.6	73.8	12.8	11.9	0.39	1.247
Glee	HRS	81.2	67.5	13.1	12.1	0.46	0.811

[a]Classes are HRS: hard red spring; HRW: hard red winter; SWS: soft white spring; SWW: soft white winter.

decreased substantially over time. Assessed as ΔL^*, the mean across varieties and hydration levels were 10.9 (data not shown). However, individual varieties ranged from 6.3 (Xerpha) to 16.6 (Glee). Soft Svevo exhibited a relatively low level of change, 8.0.

Across all varieties, noodle sheet brightness decreased with increasing hydration level, although the ranges were relatively small (86.4–88.8 at 0 hr; 75.0–0.79.0 at 48 hr (Figure 1, Supporting Information Figure S1). Compared to variety and time, the effect of hydration was considered of far less importance. Two-way interactions were the result of some modest nonparallel slopes and rank changes over time.

Mean a^* values generally began slightly negative and ended (mostly) slightly positive after 48 hr (Figure 2). These results indicated that the noodle sheets were, in general, not particularly green nor red, but near the neutral "gray" a^* value of zero. Over time, all samples became slightly more red. The variety Glee exhibited the greatest mean a^* value at 48 hr (3.7). Soft Svevo at 48 hr, averaged across hydrations, was −0.3, and even though it was visually yellow, the color analysis indicated that it essentially lacked a green-red component.

Hydration level had a small overall effect, with some slight overall increase in a^* from 30% to 32% hydration (data not shown). Interactions were again relatively small in comparison with the main effects. These interactions were primarily minor rank changes in varieties across time, and rank changes in hydration levels over time. No consistent patterns in the interactions were observed for changes in a^*.

All noodle sheets increased in b^* during the first 2 hr of storage (Figure 3, Supporting Information Figure S2). Quite often, little additional change in b^* occurred after this initial change. However, in a few varieties, there was a small additional increase (especially at 34% hydration). In contrast, for WB456, Farnum, and Glee, there was a marked decrease in b^* after about 6 hr of storage. The effect was most pronounced at the highest hydration level of 34% (Figure 3b) and also tended to occur in varieties that were inherently more yellow overall from zero to 2 hr. At 48 hr, when averaged across hydrations, the hexaploid varieties ranged about 10 units in b^* (15.2 for Xerpha to 25.3 for Farnum). As expected, Soft Svevo was the most yellow with a b^* of 33.2 (Figure 3, Supporting Information Figure S2).

Overall, the b^* values increased as hydration level increased, with 34% hydration having the greatest b^* value and 30% the lowest. Although all three hydration levels were statistically different, mean differences were relatively small. Similar to a^*, interactions that occurred in b^* were the result of minor rank changes that occurred across hydration levels and time. The other observation was that the range of b^* among varieties at 48 hr decreased with increasing hydration.

3.3 | Alkaline noodles

The whole models for L^*, a^*, and b^* were all significant with large F-values and p-values <0.0001 (Supporting Information Table S2). All main effects of each model, that is, variety, hydration level, and time, had highly significant F-values. Although varieties differed for all three color axes, and hydration had a significant effect, these factors were dwarfed by the effect of time. The F-values for "time" for all three color measurements were large and emphasized the effect that time has on noodle sheet color for all three color axes: 2602 for L^*, 973 for a^*, and 895 for b^*. These F-values were larger than the other main effects and interaction F-values, often by more than one or more orders of magnitude.

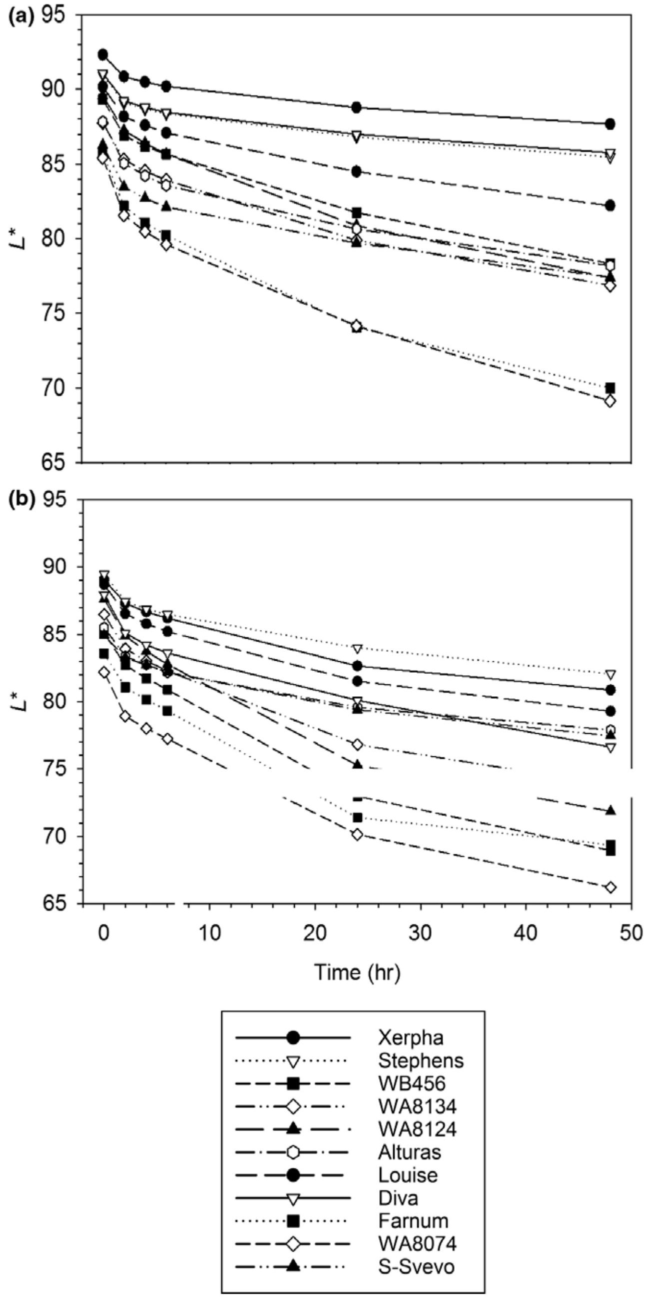

FIGURE 1 White salted noodle sheet brightness L^* of varietal samples measured at 0, 2, 4, 6, 24, and 48 hr. (a) Noodle sheets prepared at 30% hydration, and (b) noodle sheets prepared at 34% hydration. Variety identifiers are shown in the legend

Brightness, L^*, varied greatly across varieties. Xerpha produced the brightest noodle sheet with an L^* of 85.3, whereas Glee was the darkest with an L^* of 73.7 (Figure 4, Supporting Information Figure S3). Soft Svevo fell below the overall mean with an L^* of 77.9. Brightness decreased with increasing hydration levels, ranging from 82.3 at 30% hydration, decreasing to 78.0 at 34%. Mean brightness decreased markedly over 48 hr, from L^* of 85.7 to 74.3. The interaction F-values for L^* were small for the only

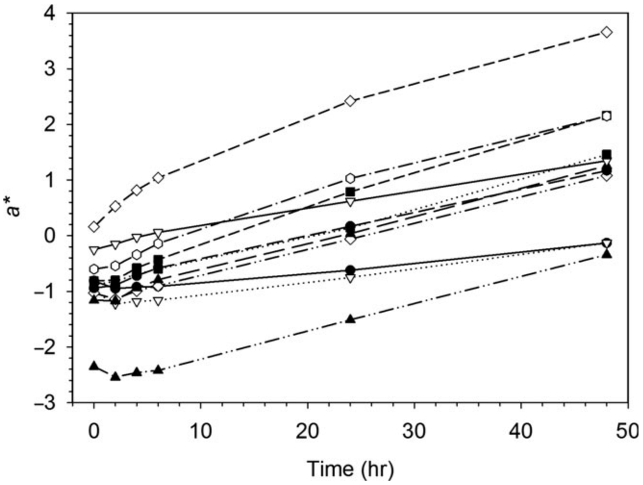

FIGURE 2 White salted noodle sheet a^* of varietal samples measured at 0, 2, 4, 6, 24 and 48 hr. Data are means averaged across 30, 32, and 34% hydration. Variety identifiers are the same as shown in Figure 1

two significant interactions, variety by hydration, and variety by time, in comparison with the main effect F-values, especially time. Like L^*, changes in brightness (ΔL^*) varied markedly among varieties (averaged across hydrations), ranging from 7.3 (Xerpha) to 17.4 (Glee) (data not shown). Soft Svevo was slightly greater than the overall mean of 11.4 at 12.0.

The alkaline pH had little apparent influence on noodle sheet a^* values, which ranged from −0.84 (WA8124) to 1.0 (Glee) across hydrations (Figure 5). The grand mean value of 1.7 was similar to that of the white salted noodle sheets at 1.2. Soft Svevo had an a^* value of −0.43, which could be considered essentially zero (neutral gray). Whereas most of the varieties were clustered between −0.51 and 0.63, Glee was the most "red" with an a^* of 1.0.

There was no apparent trend in a^* values across hydration levels (data not shown). The a^* values at 30% and 34% hydration were not statistically different. Changes over time were similar to those observed for white salted noodle sheets. Noodle sheets at the first time point were somewhat on the green side of the axis at −1.91. After 48 hr, they had shifted to the red side of the axis at 1.75.

The grand mean for b^* across all varieties and hydration levels was higher (more yellow) compared to white salted noodle sheets, but surprisingly, not dramatically so (21.4 vs. 24.5, white salted and alkaline noodle sheets, respectively). Nevertheless, hexaploid varieties differed significantly with the lowest being Xerpha at 17.8 (least yellow) vs. Farnum at 28.5 (b^* 48 hr). Soft Svevo was again markedly more yellow than the other varieties with a 48 hr b^* of 35.3 (Figure 6, Supporting Information Figure S4). Of interest, the elevated pH seemingly had no

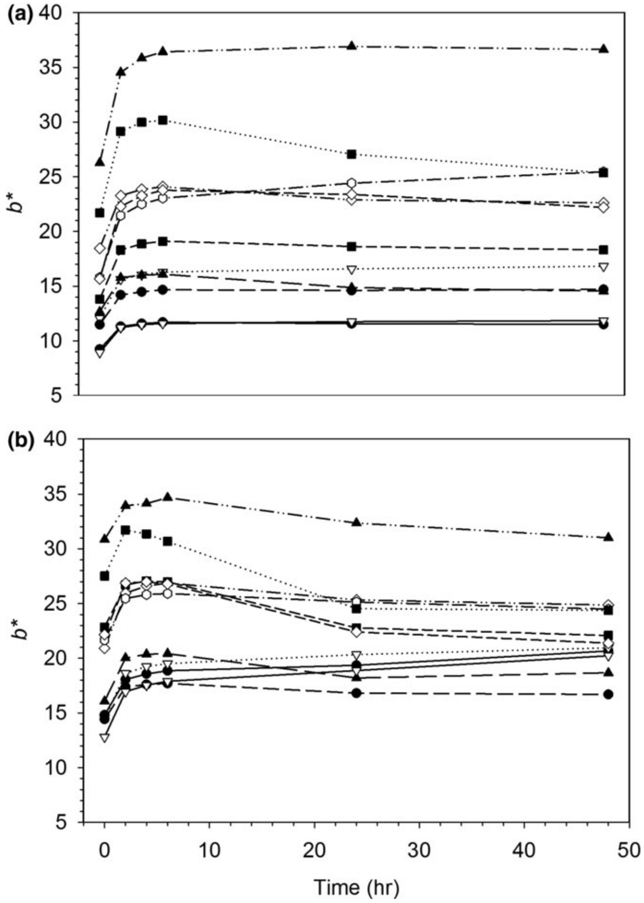

FIGURE 3 White salted noodle sheet b^* of varietal samples measured at 0, 2, 4, 6, 24, and 48 hr. (a) Noodle sheets prepared at 30% hydration, and (b) noodle sheets prepared at 34% hydration. Variety identifiers are the same as shown in Figure 1

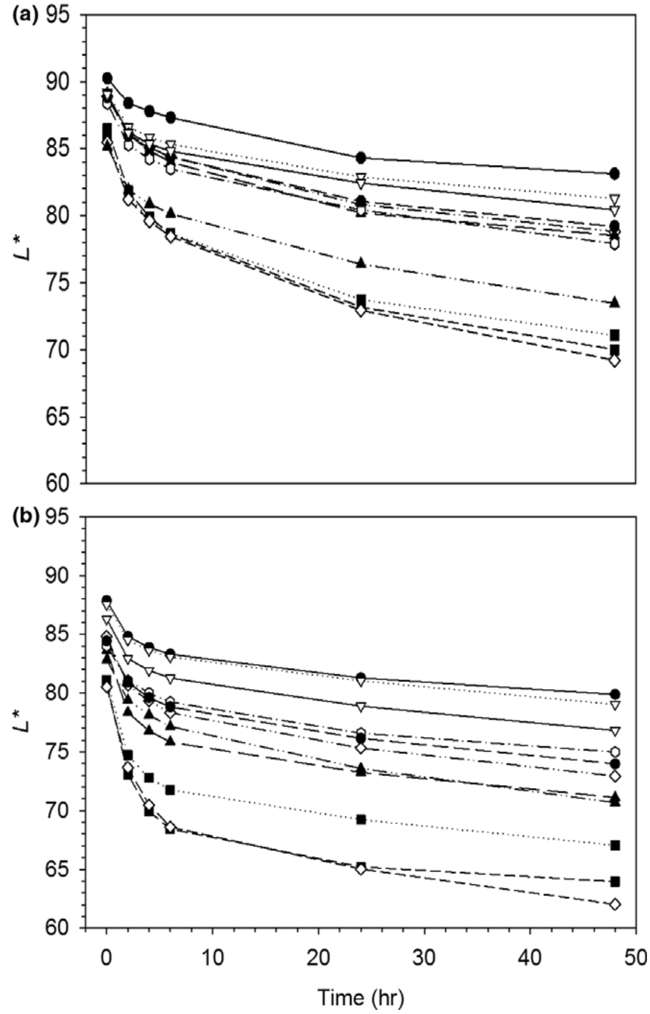

FIGURE 4 Alkaline noodle sheet brightness L^* of varietal samples measured at 0, 2, 4, 6, 24, and 48 hr. (a) Noodle sheets prepared at 30% hydration, and (b) noodle sheets prepared at 34% hydration. Variety identifiers are the same as shown in Figure 1

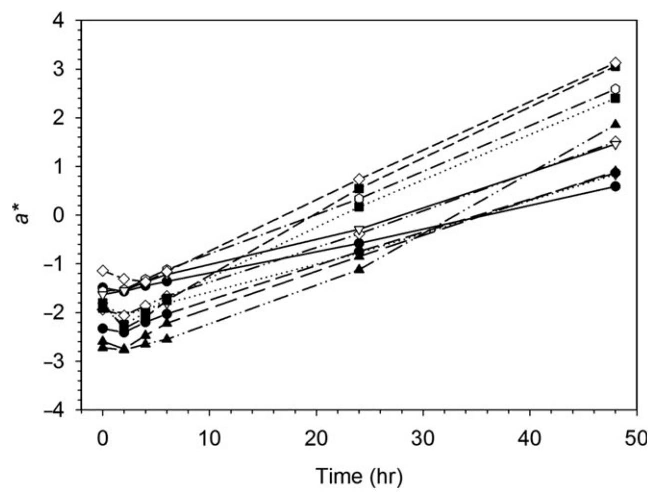

FIGURE 5 Alkaline noodle a^* of varietal samples measured at 0, 2, 4, 6, 24, and 48 hr. Data are means averaged across 30, 32, and 34% hydration. Variety identifiers are the same as shown in Figure 1

effect on Soft Svevo: Its white salted noodle sheet b^* across hydrations was identical to that of its alkaline noodle sheet at 35.3.

Although the mean b^* values increased with increasing hydration levels, the range was qualitatively small, with 30% hydration mean b^* of 19.2 and 34% hydration b^* of 24.1. The b^* values increased most over the first 2 hr; the mean b^* value at the zero time point was 19.1 and rose to 24.5 by 48 hr. The interactions between variety by hydration, variety by time, and hydration by time were considered of no particular consequence.

3.4 | Egg noodles

As seen with the prior two formulations, all whole models for L^*, a^*, and b^* were significant along with all main effects for egg noodle sheets (Supporting Information Table S3). All two-way interactions were also significant, with the exception of hydration by time for a^*. The interaction F-values, however, were small in comparison with the main effect *F*-values. In all three color dimensions, time differences were the greatest, particularly for *L** and *a**, with *F*-values of 10256 and 3080, respectively.

Although there was variation in *L** among varieties, the range was somewhat smaller than that observed for the other two noodle types (48 hr, means across hydrations) (Figure 7, Supporting Information Figure S5). Whereas the range in *L** values for white salted and alkaline noodle sheets was approximately 17 units of brightness, the range in *L** values for egg noodle sheets was 13 units. In this case, Stephens was the brightest, but was quite similar to Xerpha and Diva; Farnum and Glee were the darkest. Soft Svevo was relatively bright with an *L** of 70.5. Brightness was not markedly influenced by hydration level, with means over all varieties 71.5, 69.8 and 70.2, 38%, 40% and 42%, respectively. By far the largest effect was "time" wherein brightness had an initial *L** value of 81.0 (time zero) and then decreased to 65.2 after 48 hr (averaged across varieties and hydrations). For Δ*L**, Soft Svevo and Alturas had the smallest change in brightness (9.3 units) (data not shown). In contrast, WB456, Puma, WA8124, Farnum, and Glee had the highest and similar degree of darkening, all approximately 21 units.

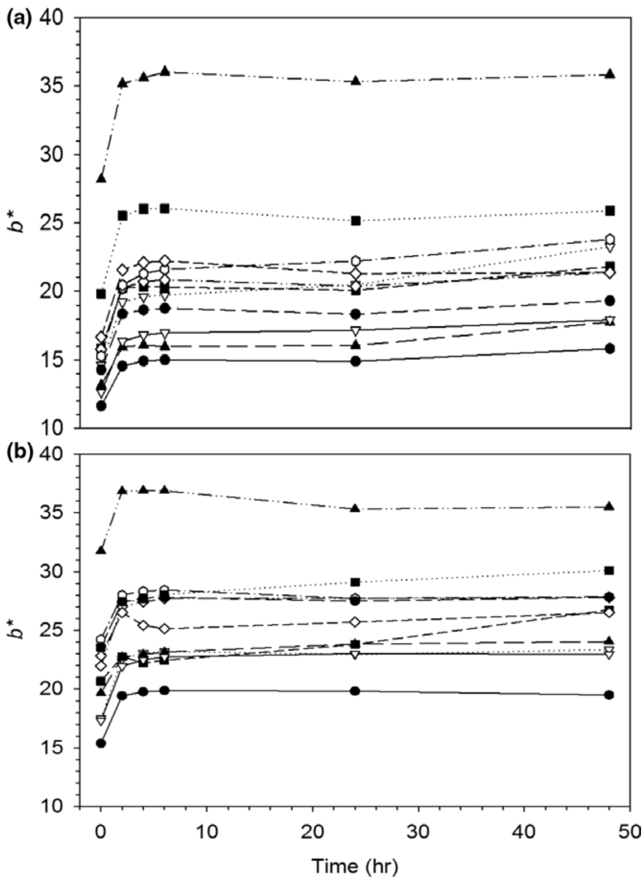

FIGURE 6 Alkaline noodle sheet *b** of varietal samples measured at 0, 2, 4, 6, 24, and 48 hr. (a) Noodle sheets prepared at 30% hydration, and (b) noodle sheets prepared at 34% hydration. Variety identifiers are the same as shown in Figure 1

Over all varieties and hydration levels, the average 48-hr *a** was 4.4—slightly "redder" than the other two noodle types (Figure 8). The *a** values varied among varieties, although all were in the positive, or red side of the scale. The varieties ranged from 2.6 (Xerpha) to 5.3 (Glee). Soft Svevo fell essentially on the mean. The two higher egg levels exhibited greater *a** values than the lowest egg level of 38%. As seen before, noodle sheets tended to become "redder" over time. The *a** level increased from 1.6 at the first reading to 4.4 at 48 hr.

Soft Svevo again exhibited the greatest overall *b** value at 48 hr (49.0), meaning it was the most yellow egg noodle sheet, whereas WA8124 and Glee were the least yellow at 32.6. Similar to the other noodle types, there was a large difference between the Soft Svevo *b** value and the hexaploid wheat varieties. As hydration increased, so too did *b**. Each 2% increase in hydration was associated with a 2–3 unit increase in *b**. Over 48 hr, the yellowness increased from a mean *b** value of 33.9 at the time zero, to 37.0 after 48 hr. As observed previously, *b** tended to increase initially, level off, and then either remain about the same or decrease; the decrease seemingly was variety-dependent.

4 | DISCUSSION

Wheat flour noodles are an important part of the diet in Asia, and their popularity is growing worldwide. Color is a primary quality criterion. Regardless of the type of Asian noodle, a high level of brightness (*L**) is universally desirable (Martin, Beecher, & Giroux, 2008; Miskelly, 1996; Moss, 1971; Ye et al., 2009). PPO activity has been considered the main factor affecting both the amount of discoloration (Δ*L**) and the absolute level of brightness (Baik et al., 1995; Davies & Berzonsky, 2003; Jukanti et al., 2003; Kruger, Anderson, & Dexter, 1994; Miskelly, 1996; Morris, 2018). For this reason, there has been considerable recent interest in the potential of durum wheat to be used in Asian noodles (Fu et al., 2006; Hatcher, Dexter, et al., 2008; Hatcher, Dexter, Anderson, et al., 2009; Hatcher, Dexter, Bellido, et al., 2009; Hung & Hatcher, 2011) because durum cultivars generally have low (often nil) levels of PPO activity (Anderson & Morris, 2001; Anderson et al., 2006; Bernier & Howes, 1994; Feillet et al., 2000; Fuerst et al., 2006a,b; Lamkin et al., 1981; Massa et al., 2007; Taranto et al., 2017). In addition to low PPO, durum wheats are known for their high natural yellow pigment content, and for this reason, they were specifically targeted toward alkaline noodles, where in bread wheats, the high pH produces a variable increase in yellow color

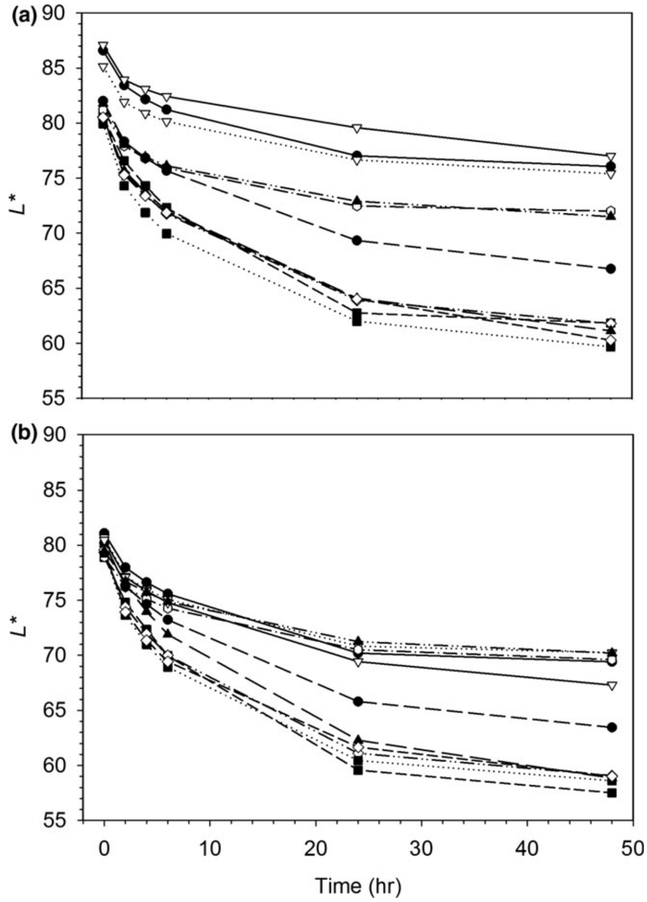

FIGURE 7 Egg noodle sheet brightness *L** of varietal samples measured at 0, 2, 4, 6, 24, and 48 hr. (a) Noodle sheets prepared at 38% hydration, and (b) noodle sheets prepared at 42% hydration. Variety identifiers are the same as shown in Figure 1

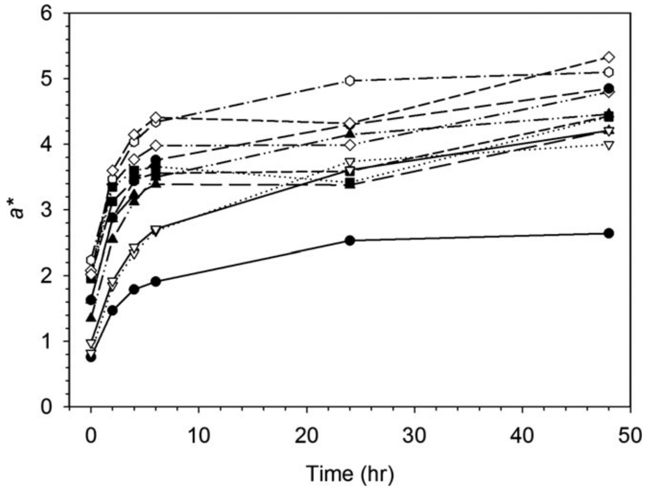

FIGURE 8 Egg noodle sheet *a** of varietal samples measured at 0, 2, 4, 6, 24, and 48 hr. Data are means averaged across 38, 40, and 42% hydration. Variety identifiers are the same as shown in Figure 1

due to the flavones apigenin–glycosides (Asenstorfer et al., 2006; Wijaya & Mares, 2012). Perhaps the primary limitation of using durum wheat in Asian noodles may lie in its very hard kernel texture. Durum milling is markedly different from soft and hard hexaploid wheat milling (Boehm, Ibba, et al., 2017; Fabriani & Lintas, 1988; Kruger et al., 1996; Morris et al., 2015; Murray et al., 2016; Posner & Hibbs, 1997), and durum semolina and flour have higher water absorption and higher levels of damaged starch than hexaploid wheat flours, especially compared to those from soft wheats (Murray et al., 2016). However, reducing flour particle size might alleviate the disadvantages of using semolina (Fu et al., 2006). The recent development of soft kernel durum wheat prompted the need to evaluate the noodle color potential of soft kernel durum in Asian noodles. To encompass a broad spectrum of applications, white salted, alkaline, and egg noodle formulations were evaluated here.

As has been repeatedly shown, essentially all wheat noodles darken over time. That being the general case, there are marked differences among varieties for brightness, *L**, and the amount of darkening, Δ*L** ("color stability"). In this study, formula did not exert a prominent differential effect on darkening. Varieties that were bright (or dark) in one formulation tended to rank the same in the other formulations. As shown previously (Morris et al., 2000), flours that produced noodle sheets with poor brightness darkened proportionally more than those that did not. However, Soft Svevo seemed to respond differently to alkaline conditions. For *L**, Soft Svevo exhibited a brightness comparatively better than the average of all other noodle sheets for white salted and egg noodle formulations. And for these two formulations, the brightness rank of Soft Svevo increased as hydration increased. However, when considering Δ*L**, Soft Svevo often had near the lowest loss in brightness at 48 hr (Δ*L**) in the white salted and egg noodle sheets, but not alkaline noodle sheets, where it was essentially equal to the variety mean.

The causes for darkening are still the subject of inquiry and debate (Morris, 2018). In the present study, there was poor correspondence between PPO activity and noodle sheet brightness. For example, Xerpha had the highest PPO activity (Table 1), but often was the brightest noodle sheet (Figures 1, 4 and 7). On the contrary, Soft Svevo had the lowest PPO, but was in general near the mean for brightness. It is unknown what factors were contributing to the noodle brightness of Soft Svevo, although it had the highest flour protein and the highest ash, whereas Xerpha had the second lowest flour protein (7.6%). Prior research has shown that flour protein content has a negative relationship with noodle brightness (Asenstorfer, Appelbee, & Mares, 2010; Baik et al., 1995; Miskelly, 1984; Miskelly & Moss, 1985; Morris, 2018; Moss, 1971). In addition to the PPO darkening mechanism, additional unknown mechanism(s)

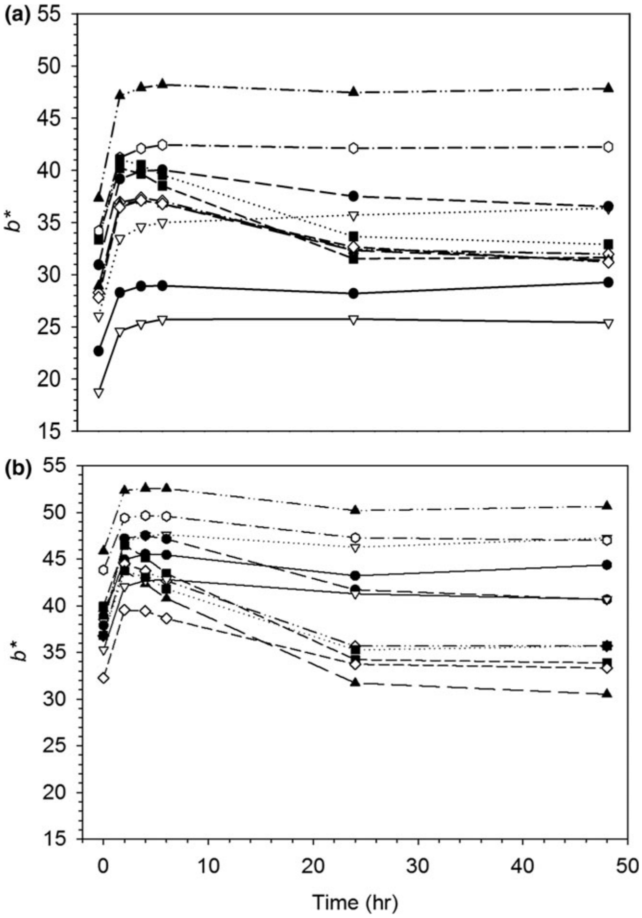

FIGURE 9 Egg noodle sheet b^* of varietal samples measured at 0, 2, 4, 6, 24, and 48 hr. (a) Noodle sheets prepared at 38% hydration, and (b) noodle sheets prepared at 42% hydration. Variety identifiers are the same as shown in Figure 1

of darkening are likely also involved in noodle color change (Fuerst et al., 2006a). The studies of Asenstorfer, Appelbee, and Mares (2009) and Asenstorfer, Appelbee, Kusznir, and Mares (2014) showed that significant discoloration could occur at near-zero PPO levels.

The a^* green-red color axis seemed to have limited involvement in determining noodle color. Although in most cases a positive numerical change reflecting a slight shift from green to red occurred, the absolute values were small and close to the "neutral" gray value of zero.

All noodle sheets exhibited some level of yellow, b^*, and all noodle sheets increased in yellowness from zero to 2 hr (Figures 3, 6 and 9). For most varieties, only minor changes occurred after 2 hr. However, in a few varieties, there was a considerable loss in yellow color from about 6–48 hr. Changes were greatest at higher hydration levels and in the white salted, and especially egg noodle sheets. These results suggest that in some varieties there may be a significant loss in yellow pigments and that the loss may be mostly eliminated at higher pH. Leenhardt et al. (2006) showed that lipoxygenase was responsible for the degradation of carotenoids in dough, and this phenomenon may be occurring here. Although the higher pH associated with alkaline noodles is known to increase yellowness, overall at 48 hr, the increase across varieties and hydration was not dramatic (21.4 vs. 24.5, white salted vs. alkaline noodle sheets). Adding egg, on the other hand, markedly increased 48-hr yellow (mean 48.4). In all cases, Soft Svevo exhibited the greatest level of yellow color, assumedly due to the natural yellow pigments associated with durum wheat. Of note, alkaline pH did not increase the yellowness of Soft Svevo; the immediate hypothesis is that Soft Svevo lacks appreciable flavones apigenin–glycosides.

5 | CONCLUSIONS

All noodles darkened over time, and most of the differences were attributable to "varieties". PPO activity was a poor predictor of noodle sheet brightness (L^*) at 48 hr for all three styles of noodle. The soft durum variety "Soft Svevo" exhibited about average brightness but tended to have low discoloration (ΔL^*) over time. The range in the green-red axis, a^*, was small, and all noodle sheets exhibited a small positive increase with most values near the neutral gray value. All noodle sheets were yellow, with Soft Svevo being markedly more yellow in all three formulations. The alkaline pH increased average yellowness by only 3 units overall, but in Soft Svevo, there was no effect. Noodle sheets of some varieties decreased in yellow color from 6 to 48 hr.

The low PPO activity of Soft Svevo did not predict an advantage in white salted, alkaline, and egg noodle sheet brightness over the "best" hexaploid wheat varieties. The reason was not resolved but may be related to marked differences in protein content among the flours. Soft kernel durum wheat exhibited some advantages over hexaploid wheat, particularly in low discoloration (ΔL^*) and high yellow color. In no way was soft durum found to be inferior to hexaploid wheat. According to color preference, Soft Svevo could be a "natural" source of creaminess (b^*) to enhance otherwise "white" flours.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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