Assessing the Potential Use of Teff as an Alternative Grain Crop in Virginia

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ABSTRACT

Teff (*Eragrostis tef* (Zucc.)) is an annual, warm-season cereal crop most notable for its gluten-free, nutrient-packed seed. Experiments were conducted in two regions of Virginia (Blacksburg and Steeles Tavern) in 2010 and 2011 to determine the grain production potential of two teff varieties (brown and white). Additionally, commercially purchased teff flour was evaluated for its suitability in producing a satisfactory baked product. Teff varieties were planted in early June and July at a seeding rate of 6 kg PLS ha^{-1}. Nitrogen fertilizer was applied at planting in the form of urea at a rate of 56 kg ha^{-1}. The experimental design was a randomized complete block with a two-way factorial treatment structure (variety and planting date) and four replications. Grain yield and nutritive value, straw yield and quality, and plant height were evaluated for each variety and planting date at Steeles Tavern in 2010. Due to failure in crop establishment and difficulties involved in threshing and processing the harvested crop, no data is available in 2010 or 2011 for Kentland or in 2011 for Steeles Tavern. In 2010 at Steeles Tavern, grain yield was significantly higher for the brown variety (367 kg ha^{-1}) compared to the white variety (97 kg ha^{-1}) for both planting dates. There was no significant difference in straw yield between varieties or planting dates with straw yield averaging 2645 and 2475 kg DM ha^{-1} for brown and white varieties, respectively. Precipitation accumulation at Steeles Tavern was higher in 2010 (greater than 10 cm) during June and July compared to 2011 and the historic average. This may explain why the plots in 2010 were able to successfully establish and out compete weeds. In the lab, four types of baked products were tested to determine the suitability of teff for baked goods. Cakes, cookies, biscuits and bread were tested with varying treatments of teff: control (100% wheat flour) and 10, 20, 30, 40 and 100% teff flour. Each treatment was replicated three times for each product. Generally, bread and cake volumes decreased as the percent of teff increased. Teff flour was best suited for use in cookie and biscuit products compared to cakes and breads since cookies and biscuits require less leavening. Overall, both experiments (field and laboratory) demonstrated the potential of teff as an alternative grain crop in Virginia. However, additional research is needed to overcome problems associated with establishment, harvest, threshing and processing

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Chapter 1

Introduction

Although teff (Eragrostis tef (Zucc.) Trotter) is largely unfamiliar to most of us; it is actually an ancient grain crop dating back to before the birth of Christ (Ketema, 1997). Originated and domesticated in Ethiopia, the genetic diversity of teff exists nowhere else in the world (Ketema, 1997). Teff is a warm-season, annual, cereal crop adapted to a wide range of environmental conditions – tolerant of drought-stressed, water-logged and low-fertility soils (Ketema, 1997). Under native habitat and for maximum production, teff performs best with a day length of 12 hours and a temperature of 10 – 27°C (Ketema, 1997). The recommended seeding rate is 15 kg ha^{-1} at a planting depth of 0.6 – 1.3 cm (Ketema, 1997). Teff germinates rapidly, emerging within 3 – 7 days (Ketema, 1997).

Teff is most known for its minute seed head, with nearly two million seeds per pound and diameter of only 0.7 to 1.0 mm (Ketema, 1997). In fact, teff in Amharic literally means “the lost seed” because if dropped, it is so easily lost (Ketema, 1997). In Ethiopia, teff is harvested by hand when the vegetative part of the plant turns yellow (Ketema, 1997). Oxen are used to trample the grass to separate the seed from the rest of the plant (Ketema, 1997). Teff is then cleaned by using a hard leather strap to waft air over the grain to separate the chaff from the mix (Zewdu, 2007).

With a population exceeding 60 million people, Ethiopia is the only country in the world where teff is intensely grown and produced for human consumption. Teff is a staple food in Ethiopia, consisting of two-thirds of their cereal diet, and is primarily used to make injera – a flat, sour, spongy, pancake-like bread. Teff can also be combined with other baking flours to produce baked products, such as muffins and cookies. While this ancient crop leaves much room for technological innovation in threshing and cleaning the grain for commercial marketing, teff has long established itself as a valuable part of the Ethiopian diet.

Notable for its nutrient-packed seed, teff is not only high in minerals and essential amino acids, but is also gluten-free, appealing to the millions of people in the United States that have been diagnosed with Celiac Disease (Ketema, 1997). Patients diagnosed with Celiac Disease, a condition that affects nutrient absorption in the inner-lining of the small intestine, cannot tolerate gluten, a protein-complex present in wheat, barley and rye (National Institute of Health, 2008; Ketema, 1997). Teff has also been linked to other health benefits, such as anemia, due to its exceptionally high iron content (Mamo, 1987).

With shifting trends in consumer preferences and an increasing demand for a healthier, wider selection of ethnic and alternative food crops, consumers are no longer satisfied with traditional crops, like corn and wheat. Instead, the demand for specialty crops has expanded beyond our borders to international cuisine. The unique taste and nutritional merit of teff has led us to believe that there is a market potential for the production of teff for grain in Virginia. With little research on this crop, much is left to be determined on establishment, productivity and management practices. Additionally, there has been little research on the use and behavior of teff in food products. Therefore, the objectives of this study seek to:

1. Assess the adaptations and grain yield potential of teff in Virginia, and
2. Determine the suitability of teff for inclusion in baked products.

Chapter 2

Literature Review

2.1 Teff: History and Overview

Indigenous to Ethiopia, teff dates back to as early as before the birth of Christ (Belay et al., 2009; Ketema, 1997), though the exact time of domestication is uncertain. Teff seed was believed to be found in the Pyramid of Dashur (3359 BC) as well as in the ancient Jewish town of Ramses in Egypt (1300 BC) (Ketema, 1997), though some archaeologists challenge this discovery, arguing that the seed may be from teff's wild predecessor Eragrostis Pilosa (D'Andrea, 2008; Degu et al., 2008) . The genetic diversity of teff exists nowhere else in the world but Ethiopia, suggesting that the origination and domestication of teff took place in Ethiopia (Ketema, 1997).

2.1.1 Taxonomy

Teff (*Eragrostis tef* (Zucc.) Trotter) belongs to the family Poaceae, subfamily Eragrostoidae, tribe Eragrosteae, and genus Eragrostis with the genus containing as many as 300 species (Ketema, 1997). Synonyms for *Eragrostis tef* include: *E. pilosa*; *E. abyssinica*; *Cynodon abyssinicus*; *Poa cerealis*; *P. abyssinica* (Ketema, 1997). The common name of the crop in Ethiopia is tef though alternate spellings include teff, taf (Tigrigna), and tafi (Oromigna) (Ketema, 1997).

2.1.2 Plant Description

Teff is an annual, C_4, self-pollinated cereal crop with a massive, shallow, fibrous root system (Ketema, 1997). The sheaths are smooth, open and distinctively shorter than the internodes (Ketema, 1997). Its ligule is short and ciliated and its lamina is slender, narrow and nearly linear with elongated, acute tips (Ketema, 1997). The panicle ranges from loose to compact with each spikelet containing 2-12 florets (Figure 1) (Ketema, 1997). The seed comes in a variety of colors from white or ivory to dark brown or red with the caryopsis ranging from 0.9 – 1.7 mm in length and 0.7 – 1.0 mm in diameter (Figure 1) (Ketema, 1997).

Figure 1. Panicle (left) and grain size (right) of the brown teff variety

2.1.3 Climate

Teff is well adapted to a wide range of environmental conditions: tolerant of both drought-stressed and water-logged environments (Ketema). Teff performs best at an altitude of 1,800 – 2,100 m with annual rainfall of 300 – 500 mm per growing season (Ketema, 1997). Sensitive to day length, teff thrives in areas with 12 hours of daylight but also does well in areas with shorter day lengths. Requiring a frost-free growing season, the emergence rate of teff increases as temperature increases with an optimum temperature within 10 – 27°C (Evert et al., 2009). In a study by Evert et al. (2009), results showed that there were noted differences in plant emergence between plots with cooler (15-23°C) and warmer temperature (23-31°C) regimes up to 9 days after planting (DAP). However, at 9 DAP, the plant densities between the two temperature regimes were not significantly different (Evert et al., 2009). Evert et al. (2009) concluded that although temperature may affect early emergence rate, temperature is not important in final stand establishment.

Despite being a C_4 plant, teff is notably less efficient at light utilization compared to other C_4 cereal crops, resulting in lower dry matter production per unit of radiation intercepted (Mengistu, 2009). Teff's sensitivity to drought depends on the growth stage during which the stress occurs and the mechanism of drought tolerance is variable within cultivars (Degu et al., 2008).

2.1.4 Production Areas

The major areas of teff production in Ethiopia include the regions of Shewa, Gojam, Gonder Wello and Welega (Ketema, 1997). Teff is widely grown across all regions of Ethiopia on a wide range of soil conditions from water-logged Vertisols to moisture-stressed, drought-prone soils (Ketema, 1997). Teff is the number one cash crop in Ethiopia and the value of teff as a grain crop has been extended to other parts of Africa, India, Australia, the United States and Canada (Ketema, 1997).

2.2 Cultural Practices

2.2.1 Seedbed Preparation

Under conventional practices, fields are plowed three to six times depending on soil type and compaction, weed competition, and climate (Ketema, 1997). Soil compaction can have an impact on yield by influencing soil nutrient and moisture availability (Gebretsadik, 2009). Weed competition can result in a significant yield loss, thus another advantage of multiple plowings prior to sowing is weed control (Habtegebrial et al., 2007). In a study conducted by Habtegebrial et al. (2007), both minimum (one plowing) and conventional (four plowings) till methods gave similar dry matter and grain yields of teff after weeds were controlled in the minimum tillage treatment. Weeds were controlled by hand, first at early tillering (four weeks after emergence) and again at the stem elongation stage (Habtegebrial et al., 2007). This indicates that repeated plowings are not necessary in order to maintain a proper seedbed but mainly affects the degree of weed infestation (Habtegebrial et al., 2007). In Ethiopia, farmers plow the fields during the short rainy season of February through March, leaving the fields bare for two to three months, and then planting begins in the middle of the rainy season between July and August (Habtegebrial et al., 2007). Lightly covering or packing the seedbed after sowing will increase seed-to-soil contact and promote germination, resulting in a higher yield (Ketema, 1997).

2.2.2 Planting Depth and Seeding Rate

The recommended planting depth for teff seed is between 0.6 and 1.3 cm (Evert et al., 2009). Planting too shallow (broadcasting) or too deep (5.0 cm or greater) should be avoided. In a study performed by Evert et al. (2009), although plants rapidly emerged after seven days at 0, 0.6, 1.3, and 2.5 cm planting depths, more plants emerged four to eight DAP at 0.6 to 1.3 cm than at a depth of 0 or 2.5 cm. Emergence rates of surface broadcasted seeds were lower due to lower seed-to-soil contact; however, seeds that were lightly incorporated into the soil resulted in lower seed loss by reducing displacement by wind or erosion. Teff requires three to seven days for complete germination (Evert et al., 2009). The recommended seeding rate according to Ketema (Ketema, 1997) is 15 kg ha^{-1} if drilled and 25-30 kg ha^{-1} if broadcasted. Broadcasting requires a higher seeding rate because 15 kg ha^{-1} would be difficult to distribute by hand due to the small seed size. Teff's small seed size can make it difficult to control distribution and population density. Seed loss is also high during harvesting and threshing because the seed is so light and can easily be blown away with the chaff (Ketema, 1997). Grain loss presents a major issue for farmers because it results in much lower yields. The national average yield of teff in Ethiopia is around 1,420 kg ha^{-1} (Ketema, 1997).

2.2.3 Fertilization

Though teff is noted to have low nutrient requirements, determining appropriate fertilization is important in optimizing crop yield. Teff's nitrogen (N) use efficiency ranges from 17 – 61% depending on the source of N as well as soil and climatic factors (Habtegebrial et al., 2007). The recommended N rate is between 40 and 80 kg ha^{-1} and varies depending on soil type (Habtegebrial et al., 2007). For example, sandy soils may require a higher N rate than clay soils due to leaching. Habtegebrial et al. (2007) performed an experiment to determine the N rate that maximized crop yield. The results showed an increase in grain yield when N was increased from 0 to 60 kg ha^{-1}, however; a decrease in yield was observed when N was increased from 60 to 90 kg ha^{-1} (Habtegebrial et al., 2007). This shows that optimum yield was obtained at around 60 – 70 kg ha^{-1}. Nitrogen application above 70 kg ha^{-1} encouraged lodging by up to 65% with a high yield in straw production and consequently low grain yield (van Delden et al., 2010).

Lodging presents a major problem for teff growers. According to S.H. van Delden (2010), susceptibility to lodging in cereal crops depends on three factors: (1) the size and (2) dynamics of the forces to which the plant is subjected, and (3) the bending strength and resistance to buckling of the shoot. Root anchorage is best during early development but because teff is supported by bundles of flexible vertical roots and because the stem does not penetrate the soil (meaning shallow crown depth), lodging is considered inevitable in later growth stages (van Delden et al., 2010).

It is also recommended that sulfur (S) be applied at 16 kg ha^{-1} along with the application of 70 kg ha^{-1} of N (Habtegebrial et al., 2007). Sulfur plays an important role in photosynthetic assimilation of N as well as N use efficiency so S fertilization may increase dry matter (DM) and grain yield (Habtegebrial et al., 2007). In a 2007 study conducted by Habtegebrial et al., the DM yield, grain yield, and panicle yield were significantly higher for the split application of combined N and S fertilizers, increasing DM and grain yield by 400 and 200 kg ha^{-1} compared to single applications (Habtegebrial et al., 2007). Ketema also supports the conclusion that split applications of N may result in increased grain yield without influencing straw yield (Ketema, 1997).

2.2.4 Irrigation

Water deficit can be a serious yield-limiting factor for crops grown in arid environments so maximizing water use efficiency is important in improving yield (Araya et al., 2010). When seeking to maximize grain production, grain water-use-efficiency is best when supplied with 8 irrigations compared to 9, 6, 4, 2, or no irrigation after the start of flowering (Araya et al., 2010). Irrigation was applied after the start of flowering at a rate of 10 – 15 mm per day after the rainy season ended and on a 3 – 4 day interval (Araya et al., 2010).

2.2.5 Weed Competition, Diseases and Pests

Weed competition can present a major challenge to the successful establishment of teff. According to Ketema (1997), it is recommended that "pre-sowing herbicides should be applied one to two weeks prior to planting while post-emergence herbicides should be applied at early tillering." Pre-sowing herbicides have shown an acceptable control level for annual broadleaf and grass weeds but do not control perennial weed species. All post-emergence herbicides control only broadleaf species and not grasses. In a study conducted by Mersie et al (1983), herbicides 2,4-D amine and MCPA (potassium salt) were applied at two levels (0.75 and 1.5 kg ha^{-1}) to teff at various growth stages to determine the impact of herbicide application on vegetative development. Until the three-leaf stage, leaf abnormalities (tubular leaves and twisted stems) as well as a high shoot dry weight reduction appeared to be a result of herbicide interference with the normal differentiation of the leaf primordial on the shoot apex (Mersie and Parker, 1983). Teff was also susceptible at the four-leaf stage; however, deformities were confined to the tillers because the main shoot apex had already started to elongate while the tiller apices were still at the susceptible stage (Mersie and Parker, 1983). There appears to be a lag phase in the development of the shoot apex between leaf initiation and panicle differentiation and so the safe stage is reported to be between that which causes leaf deformities (four-leaf stage) and that resulting in panicle deformities (six-leaf stage) (Mersie and Parker, 1983). No vegetative deformities were observed on teff plants sprayed at the five-leaf stage and also had a minimal effect on dry weights of the roots and shoots (Mersie and Parker, 1983).

Generally, disease, and pests are not major problems in teff production (Ketema, 1997). The diseases that pose the most significant threat to teff in Ethiopia are teff rust (Uromyces eragrustidis) and head smudge (*Helminthosporium miyakei*); rust causing an average loss of 10-25% (Ketema, 1997).

2.2.6 Harvesting and Threshing

Teff grain is harvested when the vegetative part of the plant turns yellow which typically varies between 60 and 120 days from planting (Ketema, 1997). It is important to harvest before the plant turns too dry to prevent yield losses from shattering (Ketema, 1997). In Ethiopia, the dried and harvested plant is laid out on hard, flat, cemented ground and oxen are used to thresh the crop (Ketema, 1997). Oxen are driven back and forth on the crop in the process of separating the grain from the head (Ketema, 1997). The grain is then separated from the straw by tossing the grain and threshed material into the air using the different aerodynamic properties, a process known as winnowing (Zewdu, 2007). The grain is manually cleaned by wafting air over the grain to blow the chaff from the mix using a hard leather strap (Zewdu, 2007).

One of the difficulties with separating and cleaning teff grain is the small seed size and weight of the grain. In order to find ways to clean the seed free of trash, it is important to understand the physical and aerodynamic properties of teff grain and straw. Terminal velocity and aerodynamic drag are two aerodynamic characteristics of a body that are useful in determining the feasibility of grain separation using air (Zewdu, 2007). In a study by Zewdu (2007), the terminal velocity and aerodynamic drag were measured by using drop and suspension methods. The results showed that the terminal velocity increased linearly from 3.08 to 3.96 m s^{-1} with increasing moisture content from 6.5 to 30.1% (Zewdu, 2007). This is because of an increase in mass per unit of frontal area (Zewdu, 2007). Inversely, the drag coefficient decreased from 0.83 to 0.65 with an increase in moisture content (Zewdu, 2007). The decreasing drag coefficient shows that the grain behaves more like a sphere with higher moisture content (Zewdu, 2007).

The terminal velocity and aerodynamic drag was also determined for teff straw (Zewdu, 2007). Short straws are a major contaminant of threshed material and are very difficult to separate because of the non-symmetrical, non-uniform density causing aerodynamic instability (Zewdu, 2007). End-node straws showed a higher terminal velocity due to the upright orientation of the straw (Zewdu, 2007). End-node straws also had the lowest drag resistant coefficient which fluctuates less with an increase in straw length (Zewdu, 2007). Node-free straws had the lowest terminal velocity (Zewdu, 2007). The conclusion of the study was that it is possible to observe an overlap in the terminal velocities between the grain and the straw materials (Zewdu, 2007). This means that complete separation of the grain and straw is not possible with methods using air (Zewdu, 2007). In fact, in many cases, the terminal velocity of end-node straws was greater than the grain (Zewdu, 2007).

2.3 Chemical Composition

While much of the world is largely familiar with teff as a forage crop, there is yet a small portion that highly regards this crop for grain. Beyond understanding its agronomic demands for successful growth and establishment, it is dually important to know the value and uses of teff following harvest. Dating back to before the birth of Christ suggests that this ancient crop has a nutrient composition that has enabled it to sustain people for generations – and indeed, it does! Comparing teff to other cereal crops reveals that there are in fact many characteristics that make teff stand apart from other cereal grains. In addition to its nutritional merit, the use of teff in various products can be better understood by investigating its chemical composition. The following sections, therefore, are dedicated to discussing the role of protein and carbohydrate fractions of wheat and teff flour in baked products. Because teff's chemical composition and baking characteristics are not well documented, the composition and characteristics of wheat flour are used as comparison.

2.3.1 Nutrient Composition

Teff has an excellent chemical composition that makes it a very nutritious alternative to other cereal crops. In terms of teff's amino acid profile, teff is higher in lysine content than all other cereals, except for oats and rice (Table 1). Lysine, the most limiting amino acid in most grains, is necessary for human health and cannot be synthesized by the human body (University of Maryland Medical Center, 2011a). Lysine must therefore be obtained from food or supplements, such as meat, cheese, fish, nuts and eggs (University of Maryland Medical Center, 2011a). For diets that exclude meat or dairy products, the use of teff could provide a good source of these amino acids. Many amino acids that are higher in teff, such as lysine, methionine and tryptophan, for example, are considered deficient in wheat. All the essential amino acids shown in Table 1 are higher in teff compared to wheat (Table 1).

One study also reported teff to have the highest iron content of all cereals though whether the source of iron is from the grain or soil contamination remains disputed (Ketema, 1997). Teff also contains more calcium, copper, zinc, aluminum, and barium than winter wheat, barley, and sorghum (Ketema, 1997). The chemical composition of teff seed compared with that of other cereals is listed below (Table 2).

Table 1. Amino acid content of teff (g/16-g N) compared with other cereals (Ketema, S. (1997). Tef: Eragrostis tef (Zucc.) Trotter. Rome, International Plant Genetic Resources Institute (IPGRI). Used under fair use guidelines, 2012)

	Teff	**Barley**	**Maize**	**Oat**	**Rice**	**Sorghum**	**Wheat**	**Pearl Millet**
Amino Acid	(g/16-g N)							
Lysine	3.68	3.46	2.67	3.71	3.79	2.02	2.08	2.89
Isoleucine	4.00	3.58	3.68	3.78	3.81	3.92	3.68	3.09
Leucine	8.53	6.67	12.5	7.26	8.22	13.30	7.04	7.29
Valine	5.46	5.04	4.85	5.10	5.50	5.01	4.13	4.49
Phenylalanine	5.69	5.14	4.88	5.00	5.15	4.90	4.86	3.46
Tyrosine	3.84	3.10	3.82	3.30	3.49	2.67	2.32	1.41
Tryptophan	1.30	1.54	0.70	1.26	1.25	1.22	1.07	1.62
Threonine	4.32	3.31	3.60	3.31	3.90	3.02	2.69	2.50
Histidine	3.21	2.11	2.72	2.10	2.50	2.14	2.08	2.08
Arginine	5.15	4.72	4.19	6.29	8.26	3.07	3.54	3.48
Methionine	4.06	1.66	1.92	1.68	2.32	1.39	1.46	1.35
Cystine	2.50							3.19

Table 2. Chemical composition of teff seed compared with that of other cereals (Ketema, S. (1997). Tef: Eragrostis tef (Zucc.) Trotter. Rome, International Plant Genetic Resources Institute (IPGRI). Used under fair use guidelines, 2012)

Chemical Element	Brown Tef	White Tef	Spring Wheat	Winter Wheat	Winter Barley	Sorghum
K (%)	0.36	0.20	0.37	0.33	0.44	0.44
P (%)	0.44	0.46	0.51	0.40	0.48	0.52
Ca (%)	0.18	0.17	<0.10	<0.10	<0.10	<0.10
Mg (%)	0.18	0.19	0.15	0.12	0.13	0.18
Mn (ppm)	21	30	53	36	12	29
Fe (ppm)	196	115	78.5	40	35	66
B (ppm)	14	13	12	12	11	17
Cu (ppm)	53	36	20	11	14	24
Zn (ppm)	67	68	60	40	45	44
Al (ppm)	83	0.12	<0.1	<0.1	<0.1	<0.1%
Sr (ppm)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1%
Mo (ppm)	0.78	0.74	0.60	0.55	0.40	0.45
Co (ppm)	0.52	0.64	0.60	0.55	0.30	0.30
Na (ppm)	220	212	195	169	392	142
Ba (ppm)	19	23.5	7.5	6	7	<1
SiO2 (%)	0.31	trace	trace	trace	trace	<0.10

2.3.2 Protein

There are many characteristics that influence flour quality in baked goods, namely moisture content, alpha-amylase, fatty acids, crude fiber and ash, and protein content and quality (Pomeranz, 1988). Protein content and quality, however, are arguably the most influential and of particular interest when comparing teff to wheat. The word protein means "primary substance" largely because they are essential to human health (Pomeranz, 1988). Likewise, protein content and quality are also essential to the production of baked goods.

Protein Content and Quality

To understand the role of protein content and quality in baking operations, one must first distinguish between the two for they are not the same and do not necessarily correlate to one another. For example, a flour may be high in protein content but lacking in the "right types" that are necessary for the structural formation of baked products, and thus lacking in quality. Take the protein content and quality of wheat and teff. The protein content of wheat ranges from 6 – 20% while the protein content of teff, which is 12 – 17%, is within this same range (Pomeranz, 1988). Solely looking at the protein content, it appears as if the behavior of teff flour would be quite comparative to the behavior of wheat flour. This of course is not the case and the difference in behavior is largely attributed to the protein quality.

Protein quality is where the characteristics of teff and wheat flour differ significantly. Although teff has high protein content and concentrations of essential amino acids, it is the protein quality that sets teff apart from wheat. In the previous section, the word 'quality' was used to describe the nutritional merits of teff compared to wheat. Here, "quality" is referred to in terms of baking quality, or the ability of the flour to perform satisfactorily in baking. Unfortunately, the proteins that make teff high in nutritional quality offer very little when it comes to their role in producing a satisfactory baked good.

Evaluating protein quality based on the end-use product rather than the nutritional aspects is what makes wheat so much better to bake with when compared to teff. Even among different wheat varieties, flours may have the same protein content but behave much differently in baking operations (Pomeranz, 1988). This is why it is important to select appropriate flour that has been processed from a wheat variety bred for a specific end-use in mind. Wheat flours used for cakes and breads, for example, would not produce an appealing cookie (Pomeranz, 1988). So what is the protein responsible for such differences in flour quality? Qualitative differences in types of flours are the result of gluten proteins which wheat contains and teff does not.

Gluten Proteins

Gluten, as mentioned above, is the protein complex that determines the baking quality of various flours. Despite differences in protein content and quality, the general observation is that as gluten increases on a total protein-basis, protein content also increases (Pomeranz, 1988). As a result, the amino acids characteristic of gluten also increase with grain protein content (Pomeranz, 1988). Manipulation of the gluten level is largely a function of agronomic practices, such as soil nutrient levels and growing conditions during kernel development (Pomeranz, 1988). The quality of gluten depends primarily on gluten composition (Pomeranz, 1988). Gluten proteins are generally characterized by their high content of proline (Pro) and glutamic acid (Glu) amino acids (see Table 3) (Pomeranz, 1988). This can be observed in wheat by contrasting the levels of proline and glutamic acid in gliadin, glutenin and residue proteins, collectively known as gluten proteins (See Table 3) (Pomeranz, 1988). Conversely, the main non-gluten, soluble proteins of the endosperm are albumin and globulin (Pomeranz, 1988).

Intimately involved in the baking process, gluten proteins are essential to structure development of the product under consideration. Responsible for binding approximately 31% of the total water absorbed by the dough, gluten-forming proteins contribute to the formation of the dough structure by providing a matrix in which starch granules are embedded (Hui, 2006). As the temperature increases during baking, the gluten proteins undergo denaturation as they lose their water-binding ability (Hui, 2006). This occurs at about 140-158°F (Hui, 2006). The water bound by the proteins is then released and transferred to the starch for starch gelatinization (Hui, 2006).

As the temperature exceeds 165°F, the gluten films that surrounded the individual gas vacuoles are transformed into a semi-rigid structure resulting from the swollen starch (Hui, 2006).

The rheological properties of wheat dough are essential to many of the food uses of wheat flour, such as leavened and pocket breads, cakes, cookies, pasta and noodles (Pomeranz, 1988). Different dough types are needed depending on the need for extensibility, resistance to stretching, mixing tolerance, or ability to enclose gas bubbles in uniform, thin films of dough (Pomeranz, 1988). Gluten proteins are particularly well suited for bread-making due to solubility and inter-protein bonding which produces these unique, viscoelastic properties (Pomeranz, 1988). Such properties can be explained by gluten's high aggregation tendencies resulting from: (1) the hydrogen bonding potential of the large number of glutamine side chains, (2) the potential for apolar bonding of many nonpolar side chains, and (3) low ionic character (Pomeranz, 1988). Consequently, gluten proteins are usually insoluble near their isoelectric points, where they have equal numbers of positive and negative charges in most aqueous solvents (Pomeranz, 1988). In fact, gluten proteins have so few chains capable of ionization that they do not develop large excess charge even at low pH and any repulsive forces between molecules are easily diminished by the greater ionic strength of the solvent (Pomeranz, 1988). As a result, even moderate concentrations of salt may cause the proteins to precipitate out of the solution (Pomeranz, 1988).

Table 3. Proportions and amino acid contents (g/16-g N) of the major protein fractions of wheat flour (Pomeranz, Y. (1988). Wheat : chemistry and technology. St. Paul, Minn., USA, American Association of Cereal Chemists. Used under fair use guidelines, 2012)

			Soluble Proteins		**Gluten Proteins**		
	Wheat	**Flour**	**Albumin**	**Globulin**	**Gliadin**	**Glutenin**	**Residue Protein**
Extracting Solvent			Water	0.5M NaCl	70% Ethanol	0.5M acetic acid	
Proportion %		100	15	3	33	16	33
Tryptophan	1.5	1.5	1.1	1.1	0.7	2.2	2.3
Lysine	2.3	1.9	3.2	5.9	0.5	1.5	2.4
Histidine	2.0	1.9	2.0	2.6	1.6	1.7	1.8
NH3	3.5	3.9	2.5	1.9	4.7	3.8	3.5
Arginine	4.0	3.1	5.1	8.3	1.9	3.0	3.2
Aspartic acid	4.7	3.7	5.8	7.0	1.9	2.7	4.2
Threonine	2.4	2.4	3.1	3.3	1.5	2.4	2.7
Serine	4.2	4.4	4.5	4.8	3.8	4.7	4.8
Glutamic acid	30.3	34.7	22.6	15.5	41.1	34.2	31.4
Proline	10.1	11.8	8.9	5.0	14.3	10.7	9.3
Glycine	3.8	3.4	3.6	4.9	1.5	4.2	5.0
Alanine	3.1	2.6	4.3	4.9	1.5	2.3	3.0
Cystine	2.8	2.8	6.2	5.4	2.7	2.2	2.1
Valine	3.6	3.4	4.7	4.6	2.7	3.2	3.6
Methionine	1.2	1.3	1.8	1.7	1.0	1.3	1.3
Isoleucine	3.0	3.1	3.0	3.2	3.2	2.7	2.8
Leucine	6.3	6.6	6.8	6.8	6.1	6.2	6.8
Tyrosine	2.7	2.8	3.4	2.9	2.2	3.4	2.8
Phenylalanine	4.6	4.8	4.0	3.5	6.0	4.1	3.8

The suitability of a dough or gluten for a product can be determined through product testing (Pomeranz, 1988). For baked goods, achieving a satisfactory product with gluten-free flour may present a challenge. Investigating the baking behavior of various combinations of gluten-free flours with wheat flour may reveal the level at which a product can contain gluten-free flour and still yield an acceptable product. For now, it is worth mentioning the non-gluten proteins that constitute teff's high protein flour.

Soluble Proteins

Proteins that are not gliadin or glutenin polypeptides are called soluble or non-gluten proteins and consist primarily of albumins and globulins (Pomeranz, 1988). Due to a higher concentration of amino acids, such as lysine, and lower glutamine content, soluble proteins are more nutritious than wheat proteins (Pomeranz, 1988). The fractional composition of proteins in teff in the order of their fractional importance is as follows: 44.55% glutelins, 36.6% albumins, 11.8% prolamin and 6.7% globulins (Gamboa, 2008; Ketema, 1997). It is important to note that although teff has a high fraction of glutelin proteins, the proportion of the protein classes force them to function very differently than those of wheat (Tilley, 2011). Wheat prolamins and glutelins (gliadin and glutenin) contain a specific sequence of amino acids that elicit a response in individuals susceptible to Celiac Disease (Tilley, 2011). The prolamins and glutelins present in teff are genetically distant from the subfamily of grains containing wheat, barley and rye due to the differences in amino acid sequence (Tilley, 2011).

When dissecting the pericarp, testa, aleurone, endosperm and germ, amino acid analysis of each part suggests that protein classes differ throughout the kernel (Pomeranz, 1988). The proportion of amino acids decrease and the nitrogen content increases as you move from the center of the wheat kernel to the outer endosperm (Pomeranz, 1988). The distribution of protein in teff, as well as the percentage of ash and mineral elements, is higher in the pericarp than in the endosperm (Ketema, 1997). Flours generally contain less lysine, arginine, glycine and alanine but more glutamate and proline than the whole grains from which they were derived (Pomeranz, 1988). Albumins include the flour proteins that easily dissolve in water and have significantly more lysine, aspartic acid, threonine, alanine and valine than do gliadin and glutenin fractions (Pomeranz, 1988).

For many food applications, and particularly for the purpose of analyzing the baked products of teff and wheat flour, the wheat proteins of interest are gluten, the relatively insoluble protein complex. Gluten contains about 80% of the total (10-14%) protein in wheat grain (Pomeranz, 1988). With teff lacking in gluten and high in soluble proteins, the baking characteristics will be much different than those of wheat.

2.3.3 Carbohydrates

Like proteins, carbohydrates also play an intricate role in the baking process. Constituting of nearly 80% of the total dry matter of the wheat kernel, carbohydrates are widely distributed in nature and the most abundant component of cereals and cereal food products (Pomeranz, 1988). Present in a variety of monomer and polymeric forms, they function in many structural and metabolic roles (Pomeranz, 1988). Based on the polymeric nature of the carbohydrate, they are classified into mono-, oligo- or polysaccharides (Pomeranz, 1988).

Monosaccharaides, the monomeric form of carbohydrates, that are most commonly found free or as a component of a polymer in cereals include D-xylose, D-glucose, and D-fructose (Pomeranz, 1988). When two or more monosaccharides condense, a disaccharide is formed (Pomeranz, 1988). Maltose and sucrose are the most common disaccharides found in cereal products (Pomeranz, 1988). Formed naturally or from the degradation of larger polymers, oligosaccharides are characterized by low-molecular-weight polymers that contain a limited number of monosaccharides (Pomeranz, 1988). Conversely, a polysaccharide is a high-molecular-weight polymer formed by the condensation of monosaccharides either in linear or branch-chained structures (Pomeranz, 1988). Cellulose and hemicellulose are examples of naturally occurring polysaccharides that constitute or are part of plant cell walls (Pomeranz, 1988). Additionally, starch and glycogen are examples of storage polysaccharides which serve as metabolic reserves in plants and animals (Pomeranz, 1988). Structural polysaccharides, cellulose and hemicellulose, cannot be digested by gastrointestinal enzymes and are therefore known as dietary fiber (Pomeranz, 1988).

Starch

Starch is the most abundant polysaccharide in wheat flour, consisting of 63 – 72%, followed by hemicellulose, cellulose, and pentosans (water-soluble and insoluble) in lesser amounts (Pomeranz, 1988). Starch is found in discrete, partially crystallized granules within cells of the endosperm. Modern milling practices that are designed to remove the bran and germ leave behind a flour consisting primarily of endosperm and thus rich in starch. Starch content is inversely related to protein content so flours high in starch will have low protein content, and vice versa (Pomeranz, 1988).

Starch granules undergo a series of changes when heated in an aqueous solution that are essential to the functionality of baked products (Pomeranz, 1988). These transformations in the starch granule are referred to as gelatinization and pasting. In the process of gelatinization, the starch granule undergoes two phenomena, (1) a loss in crystalline structure and (2) swelling (Pomeranz, 1988). The role of starch is to serve as a "temperature-triggered water sink", expanding and gelatinizing with increasing temperatures (Pomeranz, 1988). The behavior of starch and its ability to undergo these changes, however, is greatly influenced by water availability (Pomeranz, 1988).

In most baked products, water availability is limited, particularly with respect to starch gelatinization (Pomeranz, 1988). Furthermore, other ingredients may also affect starch gelatinization by competing with starch for water (Pomeranz, 1988). Sugars, salts and lipids (surfactants) are reported to influence starch gelatinization (Pomeranz, 1988). Systems with high concentrations of sugars and shortening, such as in cookies for example, are reported to decrease starch granule deformation by restricting water-availability to the starch granules (Pomeranz, 1988). In systems with high moisture, such as the case in cakes, starch granules were observed to be highly folded and deformed (Pomeranz, 1988). Specifically, gelatinization was reported to be only 4% in cookies compared to nearly complete gelatinization in cakes (Pomeranz, 1988). Sucrose delays gelatinization by increasing the temperature at which gelatinization occurs, consequently affecting batter consistency and quality of the resulting product (Pomeranz, 1988). Changes in starch granules, therefore, depend not only on temperature but water-availability, which is largely controlled by other ingredients (Pomeranz, 1988).

Dietary Fiber

The main components of the cell wall material in the wheat plant that are not digested by the human digestive track are called non-starch polysaccharides, also known as dietary fiber (Pomeranz, 1988). Although the main polysaccharides of the cell wall are arabinoxylans and glucans, there are also small but significant amounts of cellulose (Pomeranz, 1988). The wheat endosperm is highest in the amount of arabinoxylans which accounts for 86% of the endosperm's cell wall polysaccharides (Pomeranz, 1988). On the other hand, the cell walls of the lignified bran layers contain considerable amounts of cellulose (Pomeranz, 1988).

Cellulose is the principle polysaccharide in plants. Richest in the straw, cellulose content is as much as 40-43% in the straw of the wheat plant (Pomeranz, 1988). Equally present is hemicellulose (Pomeranz, 1988). In the wheat endosperm, cellulose accounts for approximately 4% of the total cell wall while accounting for as much as 29% of total non-starch polysaccharides in the bran's cell walls (pericarp, testa and aleurone) (Pomeranz, 1988).

Pentosans

Among the non-starch polysaccharides present in wheat flour, arabinoxylans are not only the main component of the non-cellulosic, non-starch polysaccharides but have received the most attention due to their influence on flour quality (Pomeranz, 1988). Arabinoxylans are a group of a larger classification called pentosans which is the term assigned to these complex materials based on their solubility (Pomeranz, 1988). Pentosans are therefore divided into water-soluble and water-insoluble flour pentosans (Pomeranz, 1988).

Due to inconsistent extraction and purification procedures, there is a lot of variability on the chemical nature of pentosans in flour (Pomeranz, 1988). One fact that seems to be of general consensus, however, is that arabinoxylans are the major constituent of purified pentosans (Pomeranz, 1988). On average, wheat flour contains 2 – 3% total pentosans, of which one-third to one-half are extractable in water (Pomeranz, 1988). This fraction of wheat pentosans is water-soluble (Pomeranz, 1988). The water-insoluble fraction of the flour pentosans is called hemicellulose and the reason for their insolubility is not fully understood (Pomeranz, 1988). The insoluble hemicellulose of the wheat's endosperm is known as the starch tailings fraction and the pentosan content of these tailings is relatively low (Pomeranz, 1988).

Even though pentosans constitute only a minor fraction of wheat flour, their extremely hydrophilic nature has made them functionally relevant in doughs and batters (Pomeranz, 1988). The extent of water absorption depends on the degree of starch damage and protein content, though pentosans were frequently found to absorb up to 10 times their weight in water (Pomeranz, 1988). During dough mixing, the pentosan components can become complex as a result of pentosan-pentosan or pentosan-protein interactions (Pomeranz, 1988). It is reported that the hydrogen-bonding capacity of the pentosans are enhanced during dough mixing which suggests that pentosans and glycoproteins serve as a bridge between major protein and carbohydrate components of the dough (Pomeranz, 1988).

2.4 Uses of Teff

After characterizing the chemical composition of teff, the uses of teff flour can now be explored. Teff is a staple food in Ethiopia, accounting for two-thirds of the population's diet (Gamboa, 2008). It is primarily used to make injera but can also be used as a cereal, porridge or baby food when mixed with soybeans, chickpeas or other grains (Ketema, 1997). Teff grain can also be fermented to produce alcohol. In addition, teff flour can be mixed with other types of flours to bake breads, muffins, and cookies.

2.4.1 Injera

"Injera" is the Amharic word for Ethiopian bread made from teff grain (Ketema, 1997). Similar in shape and texture to a pancake, the bread is porous, thin, spongy and sour-tasting and typically consumed with wot (meat sauce), lentils, faba beans, field peas, broad beans or chickpeas (Ketema, 1997). Injera's high iron and calcium content has drawn much interest from nutritionists around the world. The use of teff as a substitute flour in baked products will be thoroughly discussed in the next sections.

Injera is prepared by first cleaning and grinding the grain into flour (Refera, 2001). The grain is then cleaned by sifting out foreign material, soaking the grain for a few hours to soften the grain and then lightly pounding the grain with a pestle and a mortar (called a Mukachcha) to remove the thin seed coat (Refera, 2001). The ground grain is then left in the sun to dry on a woven mat before being ground into flour (Refera, 2001).

The flour is then mixed with water in a clay, metal or wooden container (Refera, 2001). A fermented, thin, yellow liquid (called "irsho") saved from previous fermentations is added to the mixture (Stewart and Getachew, 1962). The flour, water and irsho is then mixed to form a thin, watery paste and left to ferment for 32 – 72 hours depending on the altitude, concentration of irsho and container used (Stewart and Getachew, 1962). The paste is fermented once a considerable number of gas bubbles are trapped in the mixture. A portion of the fermented paste is then mixed with three parts water and boiled (called "absit"). This is then mixed with the fermented dough producing a clean-looking, thin "injera".

2.4.2 Baked Products

In addition to injera, teff's nutritive quality has sparked interest in other uses and part of this study seeks to explore the potential use of teff in baked products. The qualities of teff that make it a nutritional alternative to tradition cereal crops unfortunately give teff a disadvantage when attempting to achieve a desirable baked good. Despite such obstacles, the baking characteristics of teff in various products are worth examining. A combination of teff with wheat flour is one option to minimize gluten content while still producing an acceptable product. Various combinations of teff and wheat flour may be used to determine how much teff may be added to wheat flour while still baking a product similar in characteristics to those of wheat flour. After having described the role of proteins and carbohydrates in baking flour, it is important to understand the interactions of flour in the baking process of a product, as well as the role of other ingredients in baking a particular product.

2.5 The Science of Baking

Many ingredients go into the making of a delicious slice of cake, loaf of bread or batch of cookies. Traditionally, all baked products are based around the use of wheat flour, though increasingly we are integrating more diverse flours into our favorite baked goodies in an effort to meet health requirements or discover a new taste. Each ingredient contributes to the characteristics that we value in a final product and different combinations and proportions of these ingredients will produce different results. Understanding the interaction between these ingredients at various stages of the baking process is important to predicting the success of a product and modifying these ingredients, if needed. Flour quality, which is discussed in the next section, is arguably most influential in the outcome of a baked product. Following a basic understanding of flour quality, we can apply this information to the interaction of flour with other ingredients and how these ingredients may differ for individual products.

2.5.1 Baking Flour

Flour quality is the single most important determinant in the outcome of a baked product (Pomeranz, 1988). It is therefore essential to select a flour with an intended purpose in mind. Many factors influence the characteristics and quality of a flour, such as the variety and growing conditions of the crop, the milling process, and additives or special treatments to the flour (Pomeranz, 1988). Wheat is the most common flour and even among wheat, there exist hundreds of varieties, each bred for a specific trait. New varieties may be bred for disease resistance and increased yield performance, all of which are characteristics that determine quality (Pomeranz, 1988). For example, some varieties are bred for the production of a high-gluten flour suitable for bread-making while others are bred for a low-protein flour that is typically used in cookie production (Pomeranz, 1988).

Genetic manipulation may produce a wheat variety with the chemical characteristics that are desirable for a particular product but it is the milling process that stands between a hard wheat kernel and a finely ground flour (Pomeranz, 1988). The milling technique therefore contributes to flour quality, as well. For conventional milling, shearing and crushing is applied to the wheat kernel during the breaking stage in order to separate the starchy endosperm from the bran and germ (Pomeranz, 1988). By excluding the bran and germ, a wheat flour is produced consisting largely of starch and gluten proteins (Pomeranz, 1988). A starchy wheat flour that excludes the bran and germ is more desirable for baked goods (Pomeranz, 1988). On the other hand, it is said that the whole grain flours that do not exclude these components of the kernel produce an inferior baking flour (Edwards, 2007).

Inclusion of the bran and germ produce inferior flour for several reasons. First, whole grain flours which contain the bran and germ result in a higher protein content but lower quality moving from the inner to the exterior of the wheat berry (Edwards, 2007). Secondly, the bran particles tend to burst the gas bubbles that contribute to volume, reducing the amount of lift in the baked product (Edwards, 2007). Lastly, the extraction rate for brown flours is between 70% and 100% which includes nearly all of these undesirable components (Edwards, 2007).

Due to teff's small grain size, the bran and germ are difficult to remove through physical processing and separation. Teff is typically sold as a whole-grain flour which makes teff flour less than ideal for baking as a result. The ingredients used in a particular recipe may therefore need to be modified when baking with teff flour in place of wheat. For example, teff may not do well in products with a high ratio of sugar to flour and more egg or leavening agent may need to be added to compensate for the lack of gluten and poor flour quality.

2.5.2 Other Baking Ingredients

In addition to flour quality, the characteristics of a baked product are also influenced by yeast, fat, sugar, ascorbic acid, baking soda, baking powder, salt and eggs. A detailed assessment of each of these ingredients is beyond the scope of this thesis paper though it is important to grasp a basic understanding of each of their roles. Yeast feeds on the starches and sugars which in turn releases the CO_2 gas bubbles that are important for volume (Edwards, 2007). Fat softens the texture and prevents the gas bubbles from escaping (Edwards, 2007). Baking powder and baking soda are both leavening agents but differ with regard to acidity. Baking powder is simply baking soda with added acid to neutralize the strong base (Na_2CO_3) that is produced from using baking soda (Edwards, 2007). Use of one over the other depends on whether the other ingredients already contain acid to neutralize the base. Eggs help to bind the ingredients together while egg white alone helps to retain gas bubbles (Edwards, 2007). Lastly, salt adds flavor, as well as strengthens the fat and sugar mixture (Edwards, 2007). Selecting the right ingredients and in what quantity will vary depending on the desired product. The following sections discuss the ingredients and the effect of their chemical compositions on the outcome of a satisfactory cake, cookie, biscuit or bread.

2.5.3 Cakes

Often associated with our most memorable occasions, cakes are a cultural food typically consumed with family and friends. When one thinks of the desirable characteristics that describe such a cake, light, fluffy, moist and yellow are some adjectives that come to mind. So, what are the ingredients and chemical compositions that give a cake these irresistible qualities? Cakes are typically characterized by a high level of sugar in the formula in addition of high levels of water. Starch gelatinization during the baking process is what makes cakes such a light product.

For a soft and tender cake product, the flour's protein content should be no more than 7 to 9% (Pomeranz, 1988). A light and fluffy cake product requires flour free of bran and germ and as close to pure endosperm as possible. Excluding the bran and germ will result in flour that is high in starch and the starch should be intact and undamaged (Pomeranz, 1988). The flour should also be finely ground with the particles small and even in size (Pomeranz, 1988). The protein content of teff exceeds this requirement. Additionally, due to teff's small grain size, excluding the bran and germ can be difficult and therefore may produce undesirable flour for baking. It may be possible to modify other ingredients to improve teff's performance in cake production though it is unlikely that this will provide much improvement.

Flour treatment is also an important factor that is reported to affect the final cake product. Cake flours are typically treated with chlorine in order to give the flour the white appearance we are so familiar with. Studies show that Cl_2 treatments are also known to effect cake volume and symmetry, as well as reduce the stickiness of the final crumb. In one study, cakes baked with non-chlorinated flour showed radically different trends in the shape and development at the top contour of the cake compared with cakes baked using chlorinated flour (Whitaker and Barringer, 2005). For example, cakes baked with non-chlorinated flour never achieved a dome-shaped contour and the midpoint height (at x=0) never rose above 3.75cm (Whitaker and Barringer, 2005). The resulting cake was flat and sometimes dipped in the center compared to the dome-shaped contour of the cake baked with chlorinated flour (Whitaker and Barringer, 2005). Achieving a symmetrical, dome-shaped cake may be particularly problematic in cake recipes with a high sugar-to-flour ratio which may require chlorinated flour (Pomeranz, 1988).

It is very important that air is incorporated into the batter, therefore the mixing and handling of the batter greatly influences cake performance (Hoseney, 1994). The physical mixing process, for example, may alter cake consistency (Hoseney, 1994). Multistage mixing is one way of incorporating air into the batter (Hoseney, 1994). In this procedure, the sugar and shortening are first creamed together which incorporates air into the fat (Hoseney, 1994). Air in the shortening at this step is stable (immobile) and will not be released into the aqueous phases until the batter is heated and the leavening gases diffuse into the air space, thereby leavening the cake (Hoseney, 1994). The subsequent steps mix in the flour and liquids to form the final batter (Hoseney, 1994). The batter should blend easy and produce a smooth final batter (Pomeranz, 1988). Some cake batters may require extensive beating to allow air to be incorporated into the mixture (Pomeranz, 1988). Flours that contain baking soda or baking powder do not need as much beating (Pomeranz, 1988). In such a case where rising agents are present, if the batter is overbeaten, then the gas-forming reaction will occur at the beginning of the mixing but will not be retained long enough to change the structure of the baked product (Pomeranz, 1988).

The consistency of white cake batters and quality of the resulting cake were also found to be related to the changes in gelatinization temperature of the starch during baking (Pomeranz, 1988). As previously discussed, starch granules perform two major functions in product development: (1) swelling to produce a brick-like structure with viscoelastic properties characteristic of the final cake crumb, and (2) the removal of excess water from the crumb (Pomeranz, 1988). Lastly, the hemicellulosic fraction of wheat flour is found to have a beneficial effect on both the volume and internal appearance of the final product (Pomeranz, 1988). The conclusion is that a flour with high liquid-carrying capacity coupled with the ability to retain moisture in the final product appears to be essential for a good-quality cake (Pomeranz, 1988).

2.5.4 Cookies

Cookie quality can be summarized by the size of the cookie (width and height) and how the cookie bites (i.e. the cookie should have a tender bite) (Hoseney, 1994). The tender bite that we associate with a good quality cookie is the result of the use of fat, or shortening, and a soft wheat flour (Hoseney, 1994). In contrast to the chemical properties that are ideal for a fluffy cake, we typically prefer a cookie that is more soft and chewy. Just as the hydration capacity of the non-starch polysaccharides in wheat flour are principal determinants in the quality of flours intended for cake production, they are equally important for cookies (Pomeranz, 1988). The same hemicellulosic fraction that produces a good-quality cake, however, is viewed as a quality-impairing factor in cookie production (Pomeranz, 1988). For example, experiments performed with flour tailings from which the starch was removed demonstrated that water-insoluble pentosans can have a detrimental effect on cookie spread (Pomeranz, 1988). Since the pentosans do not dissolve in water, they remain in the solution and consequently result in increased cookie spread (Pomeranz, 1988).

On the other hand, flour constituents or ingredients with a great capacity for absorbing water tend to decrease cookie spread (Pomeranz, 1988). This was demonstrated in a study in which flours were supplemented with materials similar in hydrophilicity to purified tailings (Pomeranz, 1988). The study found that the substitution of hydrophilic materials reduced cookie spread, suggesting that it was the hydration capacity of the tailings that was largely responsible for the changes in cookie quality (Pomeranz, 1988). It can be concluded that differences in cookie spread are therefore attributed to differences in the tailings-fraction (Pomeranz, 1988).

Cookie spread is most important in regard to cookie packaging (Hoseney, 1994). The box that the cookies are to be packaged in is ordered months in advance with appropriate labeling, including net weight, already on the package (Hoseney, 1994). If the cookie spreads too much then the cookie cannot fit in the box without breaking and if the cookie does not spread enough then the box will be partly empty and the net weight will be inaccurate (Hoseney, 1994).

When the dough is heated in the oven, first the shortening in the dough melts (Hoseney, 1994). Dough containing melted shortening is freer to flow, giving the dough its plastic character (Hoseney, 1994). Next is the dissolving of sugar but only about half of the sugar dissolves (Hoseney, 1994). The remainder of the sugar stays in its crystalline form until the dough is more fully heated before it dissolves (Hoseney, 1994). When the sugar dissolves, it increases the volume of the solution (1 g of sugar when dissolved in 1 g of water produces 1.6 cm^3 of solution) (Hoseney, 1994). Starch gelatinization is shown to occur at about 115°C although the cookie never reaches this temperature during baking; therefore it is assumed that starch gelatinization does not occur during cookie baking (Hoseney, 1994). Since starch gelatinization does not occur during baking in cookies, this can explain why cookies are not fluffy like cake.

So far, the parameters for determining cookie quality are largely shaped around the cookie spread. Constituents that increase cookie spread are considered quality-impairing while factors that reduce cookie spread are considered to improve quality. It can be expected that teff flour will be high in water-insoluble pentosans and will therefore have a greater cookie spread. Although cookie spread serves as a good comparative measure for evaluating differences in cookie type, greater spread does not necessarily lower consumer acceptance of the final product. Teff flour may therefore prove an acceptable substitute for use in cookie production.

2.5.5 Biscuits

While in many countries, a biscuit actually refers to what Americans call a cookie, here a "biscuit" refers to a small, chemically-leavened baked product. Since the characteristics that define a high quality biscuit in the United States are not the same for other countries use of the term, the chemical requirements will be much different. Biscuit flour should have low protein content and minimal starch damage and flour that is high in protein typically does not give a satisfactory product (Edwards, 2007).

Sometimes known as "baking powder biscuits," the flour may be pretreated with specific leavening agents (AACC International, 2009). Portions (milling streams) of soft wheat flours for use in baking chemically-leavened biscuits are often treated with chlorine gas to improve biscuit thickness and control spreading during baking (AACC International, 2009). Self-rising flours containing chemical leavening agents can be evaluated by omitting leavening ingredients and salt (AACC International, 2009). The biscuit dough should be inelastic and unresisting (Edwards, 2007). Whiteness is not a highly regarded property in biscuits (Edwards, 2007).

Characteristics similar to those discussed for cookie production also affected the quality of biscuit flour (Pomeranz, 1988). Flour containing crude hemicelluloses (water-insoluble pentosans) had greater sedimentation values, the doughs were less compressible, and the biscuits were smaller in volume with a browner crust (Pomeranz, 1988). The biscuits also had less tender crust and crumb than biscuits prepared with crude water-solubles of the same origin (Pomeranz, 1988). The inferior characteristics of these biscuits were attributed to the high hydration capacity of the crude hemicelluloses of hard wheat (Pomeranz, 1988).

2.5.6 Bread

A staple food in all countries of the world, bread is the final baked product in consideration. There are two types of breads, quick breads and yeast breads, and the main difference between these types are the products made with them and the methods and ingredients used (Cachaper, 2005a). Biscuits, cakes, and muffins, for example, are common examples of quick breads whereas French breads and whole wheat breads are considered yeast breads (Cachaper, 2005a).

The methods and ingredients used in each bread product depends on the desired outcome of the product (Cachaper, 2005a). Teff flour is considered a heavy, coarse flour and since it does not contain gluten, the sponge dough method would be more appropriate to incorporate teff into the bread dough (Cachaper, 2005a). To help with texture and volume of the teff bread, teff flour will be added in varying percentages to wheat gluten flour (Cachaper, 2005a).

The main ingredients of yeast bread are flour, liquid, salt, sugar and yeast (Cachaper, 2005a). Other ingredients that may be used are sugar, gluten, fat and antioxidants (Cachaper, 2005a). Each ingredient contributes to the making of the bread: bread flour (sets structure), yeast (leavening agent), salt (for flavor and controlling the rate of yeast growth), water (moisture), sugar (for flavor, food for yeast and browning), gluten (provides elastic and extensible properties), fat (tenderness) and antioxidants (e.g. BHA/BHT and citric acid, used to extend the shelf-life) (Cachaper, 2005a).

Bread is noted to play a significant role in contributing to nutrition by providing protein, starch, fiber, vitamins and minerals (Cachaper, 2005a). Therefore, incorporating teff into a bread system may help to promote many additional health benefits (Cachaper, 2005a). The sponge dough method is a two-step process that include sponge and dough formation (Cachaper, 2005a). Sponge formation is when the yeast is activated and fermentation occurs with the addition of bread flour

(Cachaper, 2005a). Fermentation occurs as the yeast ferments the sugars to form carbon dioxide and alcohol (Cachaper, 2005a). Dough formation is when the dough is kneaded to help form an elastic substance throughout the dough to help entrap the carbon dioxide and aid in gluten development (Cachaper, 2005a).

The properties of a good bread flour are opposite to those of a good biscuit flour (Edwards, 2007). Bread flour should have high protein content and high starch damage compared to biscuit flour (Edwards, 2007). Flour containing at least 11% protein is usually preferred for yeast-leavened breads (Pomeranz, 1988). The structure of the dough involves a gluten protein matrix which consists of strings of small starch granules that are glued together by the gluten proteins (Pomeranz, 1988). The quality of the proteins present in the flour can be measured by the gas retention properties of the dough (Pomeranz, 1988). If the baker has developed the gluten well and the proteins present in the flour are of high quality, then the ability of the gluten structure to retain carbon dioxide produced by the yeast is indicated by gas retention in the dough (Pomeranz, 1988). Loaf volume is a good indicator of gas retention properties of the dough (Pomeranz, 1988). Low protein levels in flour, poor dough development, lack of oxidation, and cold or tight doughs adversely affect the gas-holding properties of the gluten (Hui, 2006). Although albumin and globulin proteins are less important to bread-making quality than gluten proteins, a number of studies have considered their affects (Pomeranz, 1988). Studies show that albumin and globulin proteins do not appear to influence the bread-making performance (Pomeranz, 1988).

Studies found that pentosans isolated from flour tailings could increase water absorption of the dough (Pomeranz, 1988). Breads with added insoluble pentosans had smaller loaf volume and coarser grain than the control and lacked the characteristic silkiness of texture (Pomeranz, 1988). The experiment claimed that water-insoluble pentosans of wheat flour were a loaf-impairing factor though there is still no consensus on this fact (Pomeranz, 1988). Some studies showed that water-insoluble pentosans were a suitable binding agent in making bread from non-wheat flours, which lack the gluten found in wheat (Pomeranz, 1988). Not only could water-insoluble pentosans improve the baking quality of the non-gluten flours to the extent that they yielded an acceptable bread (Pomeranz, 1988).

2.6 Teff and Health

The consideration of teff's baking potential in various baked products is largely important because of the health benefits that teff offers. The chemical composition of teff flour that will present a challenge in baking a satisfactory product is also the same reason for developing interest in the use of teff in the first place. Teff is gluten-free so developing a product that can be accepted by consumers may provide a healthy alternative to individuals faced with diet restrictions resulting from their gluten intolerance. Besides being gluten-free, teff is also high in minerals and essential amino acids that are commonly found to be deficient in people's diets. For example, teff is high in iron and provides a good source of lysine that is essential to human health (Ketema 1997). The following sections will therefore discuss the health benefits of using teff flour in baked products.

2.6.1 Celiac Disease

It was originally believed that Celiac Disease was a rare childhood symptom, however; it has more recently been categorized as a common genetic disorder affecting more than 2 million people in the United States, or 1 in 133 people (National Institute of Health, 2008). Celiac disease (CD) is a digestive disease that affects nutrient adsorption in the inner lining of the small intestines (National Institute of Health, 2008). Those affected by CD cannot tolerate gluten, a protein present in wheat, barley, and rye (National Institute of Health, 2008).

In a study performed by Hopman (2008), it was found that CD patients with teff frequently incorporated in their gluten free diet reported fewer symptoms and in shorter duration as opposed to reported symptoms that were much more severe before using teff (Hopman, 2008). When teff was added to the diet, there was a significant reduction in symptoms from 58 to 17% (Hopman, 2008). This suggests that teff may be a viable alternative to other cereal crops for CD patients. Assessing the baking characteristics of teff is therefore a large component of this study and the development of acceptable gluten-free products is important to providing an alternative for these individuals.

2.6.2 Other Health Aspects

Aside from providing a gluten-free alternative for celiac patients, teff also has many other nutritional benefits. Teff is higher in calcium (.18%) than all other cereal crops which contain less than 0.1% (Ketema, 1997). Calcium is the most common mineral in the body, and bones contain 99% of this calcium in the form of calcium phosphate (University of Maryland Medical Center, 2011b). Calcium is also critical to bone strength and hardness of the teeth (University of Marlyand Medical Center, 2011). Teff may prove to be a good source of calcium, helping to supply daily calcium requirements.

Additionally, teff is believed to have high iron content (116-138 ppm) (Ketema, 1997). Iron is the building block of hemoglobin, a protein responsible for binding oxygen in the blood and transporting it from the cells to the lungs, giving blood its red pigment (Mohammed et al., 2009). Anemia is a condition resulting from iron deficiency in which people do not have enough hemoglobin to transport oxygen in the blood to the lungs (WebMd, 2009). Incorporating teff into the diet may help to address the high frequency of anemia in developing countries and throughout the world.

In a study by Mamo (1987), it is found that anemia occurs less in populations where teff is a major constituent of the diet, such as Ethiopia. The study concluded that the hemoglobin content of Ethiopians was higher in teff eaters than non-teff eaters and this is believed to be attributed to the high iron content in teff (Mamo, 1987). Despite the interesting connection between the iron content in teff and the reduced rate of anemia in developing countries, further research is needed in order to make any conclusions about this link.

As previously mentioned, teff is high in essential amino acids, such as lysine. Teff's high lysine content may prove beneficial to individuals suffering from osteoporosis (University of Maryland Medical Center, 2011a). Lysine plays a very important role in converting fatty acids into energy that the body can use, which is essential for growth (University of Maryland Medical Center, 2011a). Lysine also helps to lower cholesterol, absorb calcium and aids in the formation of collagen, a substance important for bones, connective tissues, skin, tendons and cartilage (University of Maryland Medical Center, 2011a). Individuals are very commonly deficient in lysine and some may require more than others, such as the case for athletes and vegans (University of Maryland Medical Center, 2011a). Because lysine helps the body absorb calcium, it is believed that lysine may help prevent bone loss associated with osteoporosis (University of Maryland Medical Center, 2011a). A study conducted on lab rats found that lysine, in addition to L-arginine, make bone-building cells more active and enhances the production of collagen but there are no studies cited for humans (University of Maryland Medical Center, 2011a).

2.7 Proposed Research

Teff is an ancient, staple food crop native to Ethiopia where it consists of two-thirds of the cereal diet. Both originating and domesticated in Ethiopia, teff is an annual, C_4 lovegrass with a unique set of characteristics that make it a viable option for grain production in the United States. Tolerant to a wide range of environmental conditions, teff's rapid establishment, growth and adaptability makes teff a promising grass for future grain production in Virginia. In addition to easy establishment, teff produces a minute seed head packed full of nutrition. High in essential amino acids, including lysine, the protein content of teff is 10-12% (Ketema, 1997). Teff is also notably higher in calcium content (.18%) compared to other cereal crops (<.1%) and contains more copper, zinc, aluminum, and barium (Ketema, 1997). Significantly higher in iron content than other grains, teff may prove to be beneficial to those with anemia; however, teff is most importantly gluten-free, appealing to the millions of people in the United States diagnosed with Celiac Disease (Ketema, 1997). The purpose of this study is to take a holistic approach of teff grain production from field to fork. Teff will be evaluated based on adaptability and grain yield potential in Virginia, as well as its ability to produce a satisfactory baked product.

2.7.1 Grain Yield

Average annual teff production in Ethiopia is estimated to be 1.38 million tons, yielding 1,420 kg ha^{-1} in 1991 (Ketema, 1997). The same source cited that some new and improved cultivars can yield up to 1,700 to 2,800 kg ha^{-1} on farmers' fields and 2,200 to 2,800 kg ha^{-1} on research managed farms (Ketema, 1997). Small-scale teff grain production has started in the United States, with approximately 200 acres of teff grown for grain production in Carleson, Idaho (Ketema, 1997). Growing interest in producing teff in other regions of the United States has led to the development of this study. The adaptive nature of this grass, along with the success of growers in other regions of the United States has led us to believe that teff can be established and produced locally. The objective of this study seeks to assess the adaptations and grain yield potential of teff in Virginia.

2.7.2 Baking Characteristics

The baking quality of teff flour is determined by its physical and chemical characteristics. Physical characteristics include those that affect the milling or processing of teff grain. Chaff contamination may present a challenge to improving the grade quality of teff grain. The baking potential of teff grain is also defined by its chemical composition. Protein content and quality are important factors to consider when determining end product quality. The protein content of teff ranges from 10-12%, generally containing higher amounts of amino acids than all other cereals, except oats and rice (Ketema, 1997). This suggests that teff may be suitable for baking products dependent on protein content.

Protein quality, or gluten strength, is also a principle characteristic influencing baking quality. Since teff is gluten-free, exploring methods of improving the baking characteristics of teff will be a key component of this study. Consumer acceptance of the end product will be greatly influenced by the ability of teff to imitate the baking characteristics of products that contain gluten, such as wheat. This study will combine percentages of teff with wheat flour and use various physical tests to evaluate the quality of the final product. The four baked products under consideration are cakes, cookies, biscuits and bread.

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Chapter 3

The Potential Use of Teff as an Alternative Grain Crop in Virginia

Abstract

Teff (*Eragrostis tef* (Zucc.)) is an annual, warm-season cereal crop most notable for its gluten-free, nutrient-packed seed. With more than a million tons of teff produced annually in Ethiopia and production growing in the United States, interest in teff in Virginia has led to this study of its agronomic performance. Experiments were conducted in two geographical regions of Virginia (Blacksburg and Steeles Tavern) in 2010 and 2011 to determine the grain production potential of two teff varieties (brown and white). Teff varieties were planted in early June and July at a seeding rate of 6 kg PLS ha^{-1}. Nitrogen fertilizer was applied to the entire area at planting at a rate of 56 kg ha^{-1}. Experimental design was a randomized complete block with a two-way factorial arrangement of treatments (variety and planting date) and four replications. Grain yield and nutritive value, straw yield and quality, and plant height were collected for each variety and planting date at Steeles Tavern in 2010. Due to failure in crop establishment and difficulties involved in threshing and processing the harvested crop, no data is available in 2010 or 2011 for Kentland and in 2011 for Steeles Tavern. In 2010 at Steeles Tavern, grain yield was significantly higher for the brown variety (367 kg ha^{-1}) compared to the white variety (97 kg ha^{-1}) for both planting dates. Straw yield averaged 2645 and 2475 kg DM ha^{-1} for brown and white varieties, respectively and there was no significant difference in straw yield between variety or planting date. Precipitation accumulation at Steeles Tavern was much higher in 2010 (greater than 10 cm) during June and July compared to 2011 and the historic average, which may explain why 2010 had better

establishment, growth and productivity. The experiment demonstrated that although results were variable, teff grain production in Virginia is possible with additional research.

3.1 Introduction

Indigenous to Ethiopia, teff (*Eragrostis tef* (Zucc.) Trotter) is an ancient cereal crop dating back to as early as before the birth of Christ (Ketema, 1997). Although teff is largely unfamiliar to producers in the United States, it is the most valuable crop in Ethiopia, consisting of two-thirds of their cereal diet. Teff is an annual C_4, self-pollinated crop with a massive, shallow, fibrous root system. The seed comes in a variety of colors from light to dark brown with the caryopsis ranging from 0.9 – 1.7 mm in length and 0.7 – 1.0 mm in diameter (Ketema, 1997).

Adapted to a wide range of environmental conditions, teff is both tolerant of drought-stressed and water-logged soils (Ketema, 1997). Although teff thrives in areas with 12 hours of daylight, teff has also proven to be successful in areas with shorter day lengths (Ketema, 1997). Requiring a frost-free growing season, the emergence rate of teff increases as temperature increases with an optimum temperature between 10 – 27°C (Evert et al., 2009). Teff's sensitivity to drought depends on the growth stage during which the stress occurs and the mechanism of drought tolerance is variable within cultivars (Degu et al., 2008). Supplementary irrigation may be necessary during grain development in late season, drought-prone areas of Ethiopia because this stage is most sensitive to water stress (Mengistu, 2009).

In Ethiopia, fields are plowed two to five times depending on soil type, weed competition and water-logging (Ketema, 1997). Weed competition can result in significant yield loss; therefore weed control is a major advantage to multiple plowings (Ketema, 1997). Seed-to-soil contact is essential to seed emergence so lightly covering or packing the seedbed after sowing can promote germination and increase yield (Ketema, 1997). The recommended planting depth is between 0.6 and 1.3 cm (Ketema, 1997). Planting too shallow (broadcasting) or too deep (5.0 cm or greater) should be avoided (Evert et al., 2009). If planted too deep, the seed cannot emerge due to the small seed size. If planted too shallow (broadcasting), then the seed may be displaced by wind or erosion. A seeding rate of 15 kg ha^{-1} if drilled and twice this much if broadcasted has been recommended (Ketema, 1997). Teff requires 3 to 7 days for complete germination (Evert et al., 2009).

Though teff is noted to have low nutrient requirements, nitrogen (N) fertilization is suggested in order to maximize yield. The recommended N rate is between 40 and 80 kg ha^{-1} depending on soil type with optimum yield obtained at between 60 and 70 kg N ha^{-1} (Evert et al., 2009). Nitrogen application beyond this rate promoted lodging by up to 65% with lower grain yield and higher straw production (Habtegebrial et al., 2007). Due to teff's shallow rooting depth and insufficient shoot strength, lodging presents a major problem for teff growers (van Delden et al., 2010). Pre-plant herbicides are recommended one to two weeks before planting while post-emergence herbicides should be applied at early tillering (Ketema, 1997). Pre-plant herbicides have shown an acceptable control level for annual broadleaf and grass weeds but do not control perennial weed species (Ketema, 1997). All post-emergence herbicides had good control on only broadleaf weeds and not grasses and sedges (Ketema, 1997; Mersie and Parker, 1983). Disease and pests are generally not a problem in teff production (Ketema, 1997).

Teff is typically harvested between 60 and 120 days after planting when the vegetative part of the plant turns a yellowish color (Ketema, 1997). In Ethiopia, following harvest, the plant is laid out on a hard, flat cemented surface and oxen are used to thresh the crop (Ketema, 1997). This is done by driving the oxen back and forth on the crop to separate the grain from the head (Ketema, 1997). The grain is then separated from the threshed material by tossing the grain into the air using the different aerodynamic properties of the chaff, straw and grain (Zewdu, 2007). The grain is manually cleaned by wafting air over the grain with a hard, leather strap (Zewdu, 2007). Due to the small seed size and weight of the grain, separating and cleaning the grain can be difficult.

The average grain yield in Ethiopia is estimated at 1.38 million tons per year, making teff the number one cereal crop in the country (Ketema, 1997). Teff production has moved to the United States in recent years with large-scale teff grain production in Carleson, Idaho. The adaptive nature of this grass, along with the success of growers in other regions of the United States, has led us to believe that teff can be established and produced locally. In addition to teff's grain potential, the straw is also noted to have high nutritive value as forage. The objective of this study seeks to assess the adaptations of teff, straw yield and quality, and grain yield and nutritive value at two locations in Virginia. Since teff is primarily used for forage in the United States, there is little information regarding agronomic practices of teff as a grain crop. Agronomic practices, such as threshing and grain cleaning, were largely left to our discretion. Therefore, the different techniques we employed differed among locations and years depending on success of methods used.

3.2 Materials and Methods

Small plot experiments were conducted in 2010 and 2011 at two locations in Virginia: Kentland Farm in Blacksburg and at the Shenandoah Agricultural Research Extension Center (SVAREC) in Steeles Tavern (Figure 2) to evaluate the grain production potential of two teff varieties at two locations in Virginia. Field data were collected at each location on plant height, straw yield and quality, and grain yield and nutritive value.

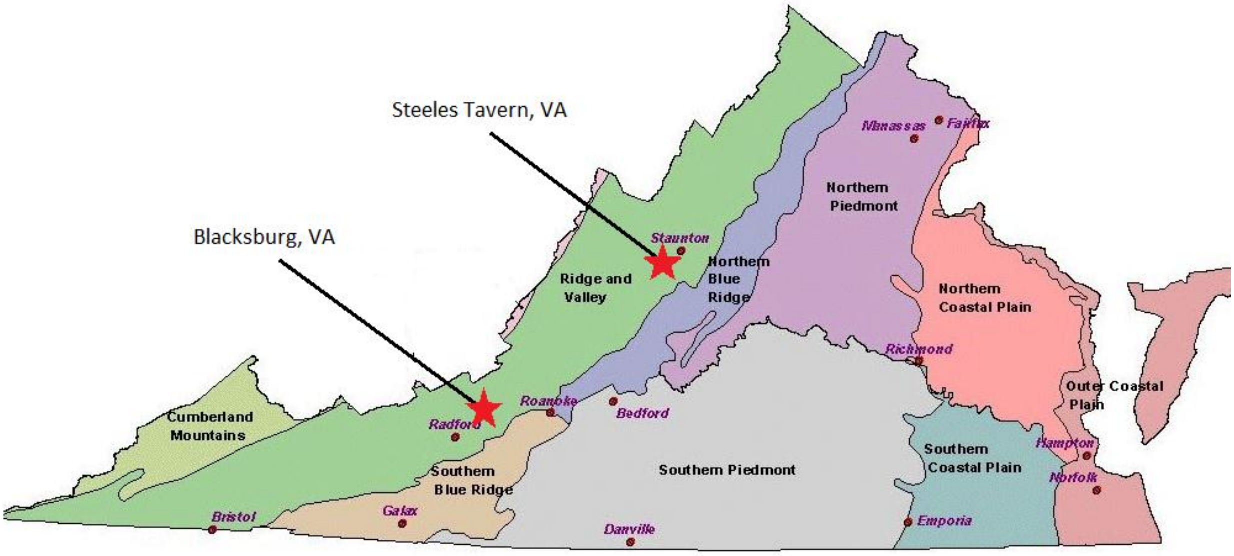


Figure 2. Experimental locations in Blacksburg and Steeles Tavern, VA for 2010 and 2011

3.2.1 Planting

Brown and white teff varieties were seeded in early June and July in 2010 and 2011 in Blacksburg and SVAREC (Table 4). The teff varieties were arranged in a randomized complete block design with four replications of each variety per planting date. Teff was seeded on a conventionally prepared seedbed using a cultipacker type seeder at a rate of 6.7 kg PLS ha^{-1}. Each plot was three-by-five meters in size. Nitrogen fertilizer was applied in the form of urea during planting at a rate of 56 kg ha^{-1}. Pre-sowing herbicide (2-4D) was applied in 2010 at Steeles Tavern for the control of broadleaf weeds.

3.2.2 Harvesting and Threshing

Plots were harvested in October when teff had reached physiological maturity and plus time for dry down. We determined dry down time by looking at the color of the upper portion of the peduncle. The grain is considered ready for harvest when the peduncle is no longer green.

Planting and harvest dates are shown in Table 4. There is currently no standard mechanized method of harvesting and threshing teff in the United States. In an effort to find the most efficient means of harvesting, various methods were tried between locations and years. In 2010 at Steeles Tavern, June and July 2010 planting dates were harvested in strips the length of the plot using a 100 cm self-propelled cycle mower. In 2011 at Steeles Tavern, however, due to thin stands and weed pressure, only a 1 m^2 area was harvested from both planting dates. The plots could not be harvested in 2010 or 2011 at Kentland due to failure in stand establishment. Each plot was harvested by selectively placing the quadrant in a harvestable area. Plant samples were placed in burlap bags for transportation and storage.

Following harvest, the samples were placed in a grain dryer at 75°C for two days (or until the seedhead could be easily removed from the plant). Once dried, samples were removed from the dryer and placed in storage until threshed. The 2010 samples were threshed using two techniques. The first method was performed by hand using a rubber mat and grout. The samples were placed on the rubber mat with the seed head facing the same direction. The grout was then used to apply friction to the seed head, causing the grain to free from the chaff. The grain was then sieved using a 0.7 to 1.0 mm sieve size to separate the grain from the trash pieces. This method of threshing was time-consuming, laborious and often difficult to effectively remove the seed from the rest of the plant. This quickly led to exploration of an alternative method of threshing. The second method involved the use of a thresher designed for small-grains, such as barley.

Table 4. Planting and harvest dates at Blacksburg and Steeles Tavern, VA for 2010 and 2011

Location	Planting Date	Harvest Date
Blacksburg, VA	June 1, 2010	October 7, 2010
	June 25, 2010	October 7, 2010
	June 2, 2011	October 11, 2011
	July 1, 2011	October 11, 2011
Steeles Tavern, VA	June 2, 2010	October 19, 2010
	June 28, 2010	October 19, 2010
	June 1, 2011	October 13, 2011
	June 30, 2011	October 13, 2011

3.2.3 Grain Cleaning

Once the grain was threshed, the seed remained mixed with a large amount of chaff and straw and needed further cleaning to separate the seeds from the chaff. Though sieving the seed provided a sort of preliminary method of seed separation, it by no means cleaned the grain to an acceptable level. One method of cleaning the grain was performed using a sorting pan. Due to the weight of the seed, the pan was used to apply vibration, causing the seed to fall to the bottom of the pan and the chaff to shift to the top. Lightly blowing on the chaff effectively removed the chaff and trash pieces from the rest of the seed, as well. Due to the number of samples, this method was too onerous and time-consuming to perform on all samples. This therefore led us in search of an alternative, mechanized method of grain cleaning.

Figure 3. Clipper Office Tester grain cleaner used to separate and clean teff grain samples

The solution to finding a mechanized method of grain cleaning was the Clipper Office Tester (Figure 3) (A.T. Ferrell Company, Inc., Bluffton, IN.). The Clipper Office Tester is used for cleaning, grading and sizing more specialized seeds, such as flower and vegetable seeds. It was recommended that the Clipper Office Tester would also serve the purpose of cleaning small grains, such as teff. The Office Tested was used to clean all 2010 samples. The machine is an accurate, tabletop two screen Air-Screen Cleaner used for small lot cleaning, testing or sampling. For teff, a 22 x 22 unit square screen was used for the top screen, and a 6 x 36 rectangle screen was used for the bottom. The air was set on the middle pulley at approximately ¼ to ½ vents. Each sample was run through the machine twice. Once the grain was cleaned to a suitable level, the samples were sent to Medallion Labs (Minneapolis, MN) for nutrient analysis (*See* chapter four for nutrient analysis of teff grain samples).

3.2.4 Straw Yield and Quality

In 2010, in addition to grain, straw yield and quality were also determined on samples collected from Steeles Tavern. Straw yield was determined on a dry matter basis following grain threshing. For nutrient analysis, sub-samples were obtained from the straw yield samples and were ground to pass through a 1 mm screen using a Wiley sample mill (Swedesboro, NJ). Samples were analyzed for neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP) (Cumberland Valley Analytical Services, Inc., Maugansville, MD).

3.2.5 Plant Height

Plant height was determined in 2010 and 2011 at Steeles Tavern and Kentland by measuring from the base of the plant to the sheath of the flag leaf. Plant height was collected to determine if there was a correlation between height and grain yield.

3.2.6 Statistical Analysis

Data was analyzed using a two-way ANOVA procedure in JMP software (JMP, 2010). The effect of treatment and location on plant height, straw yield and quality, and grain yield were tested along with any possible interactions between effects. The standard error, that is the amount of variation from the mean for each effect, is represented by the error bars in each of the graphs. The effects were fixed and the significance level was tested at 5% unless otherwise noted.

3.3 Results and Discussion

3.3.1 Environmental Conditions

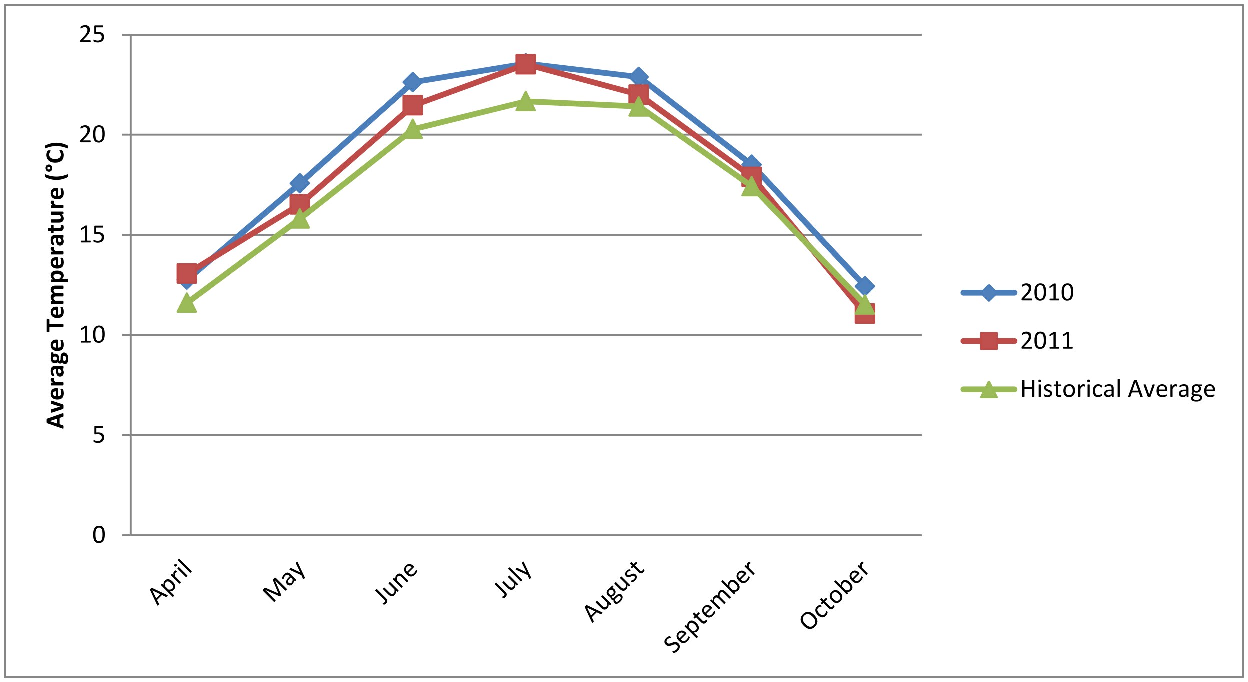
Blacksburg

In 2010 and 2011, the temperatures were higher than the historic average throughout the entire growing season, though only by a few degrees (Figure 4A). The temperatures in 2010 were slightly higher than 2011 though not by much. Precipitation accumulation, however, was highly variable between months, years, and historic averages (Figure 4B). At planting in 2010, precipitation was much lower in June and July compared to the historic average. Precipitation was then much higher than the historic average in August and September. The June planting in 2011 received even less rainfall than 2010 and was therefore much lower than the historic average. In July, rainfall was only slightly lower than the historic average and much higher than July 2010 rainfall.

SVAREC

At planting in 2010 and 2011 at the SVAREC, the temperatures in June and July were both modestly higher than the historic average (Figure 5A). The temperature was much lower in September of 2010 than both 2011 and the historic average. The precipitation in 2010 was higher than both 2011 and the historic average, steadily increasing from April through August (Figure 5B). The rainfall then decreased in August and nearly ceased altogether in October. Precipitation in 2011 was lower than 2010 but nearly matched precipitation accumulation for the historic average. Rainfall steadily increased from April through August and then plummeted in October.

A.



B.

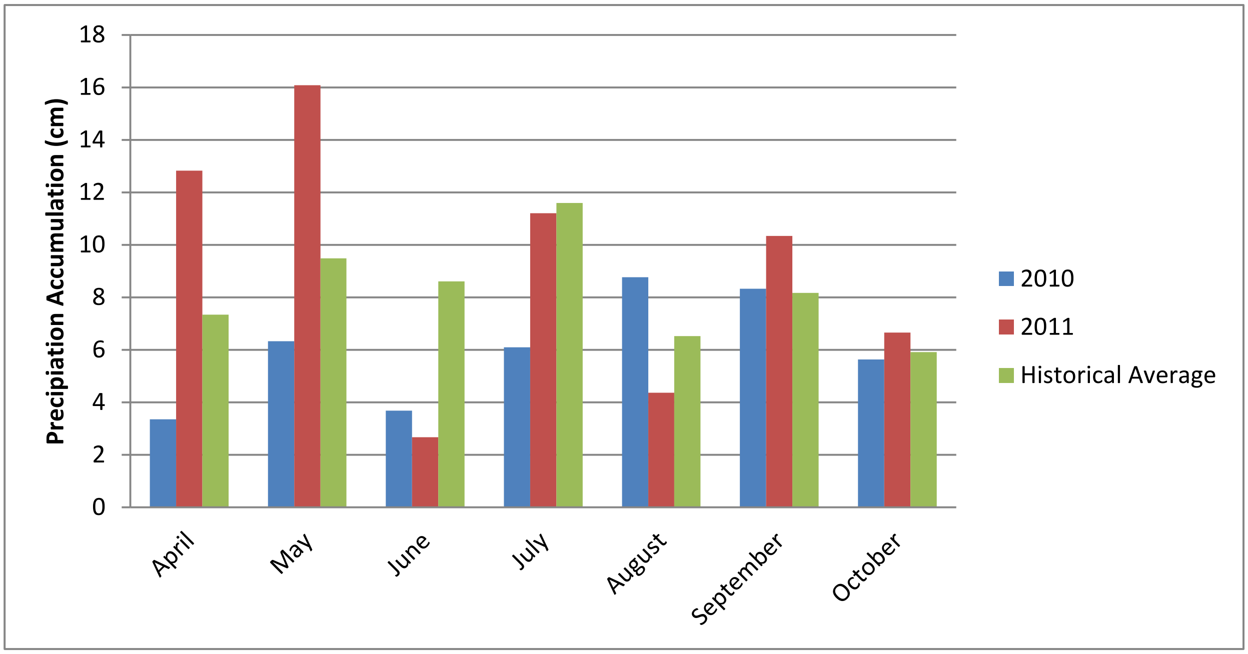
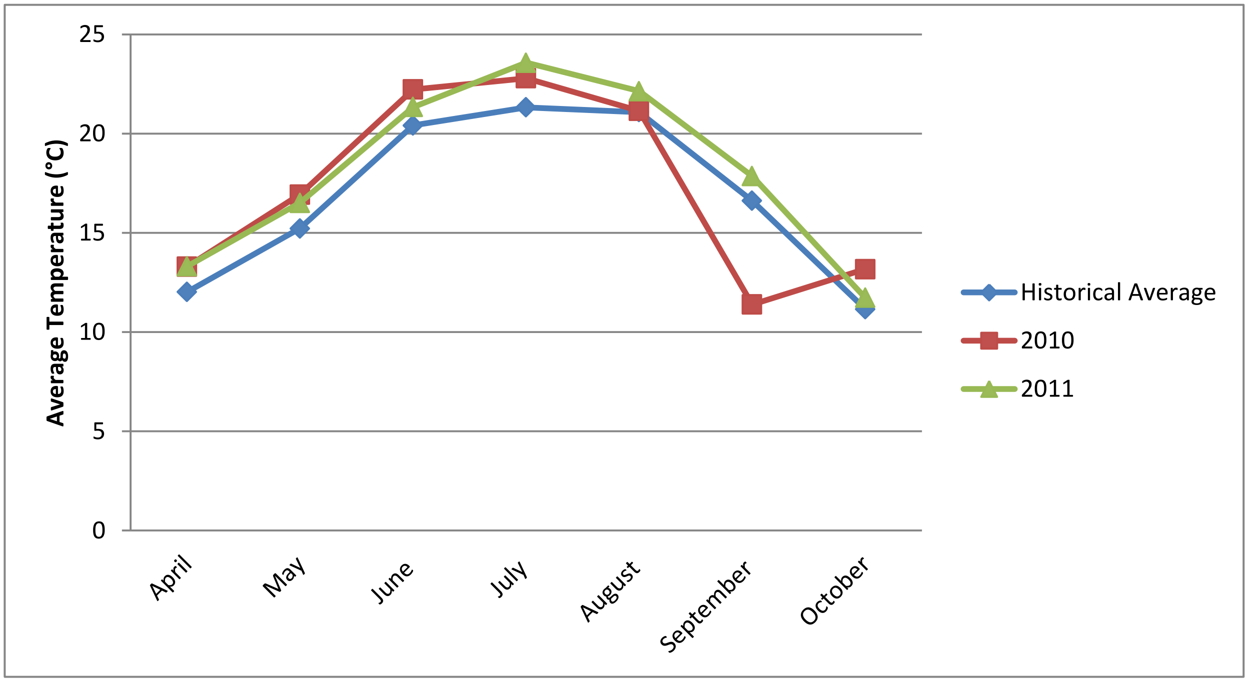


Figure 4. Monthly and historic average temperature (A) and precipitation (B) recorded in Blacksburg, VA during 2010 and 2011

A.



B.

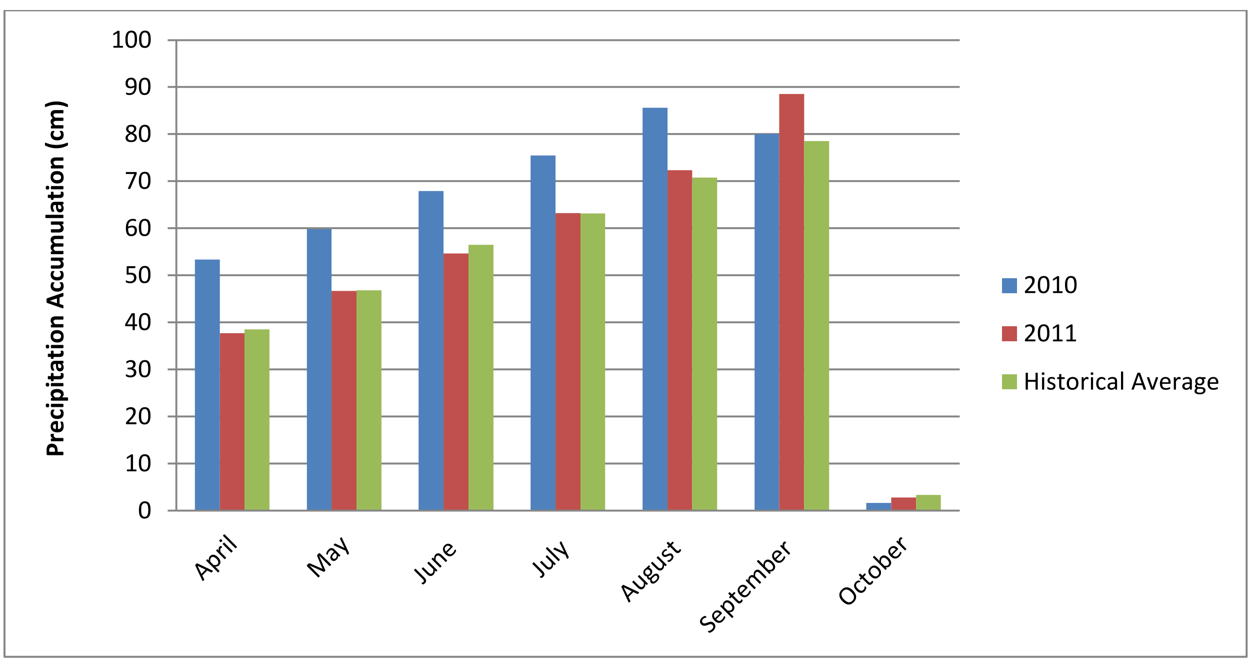


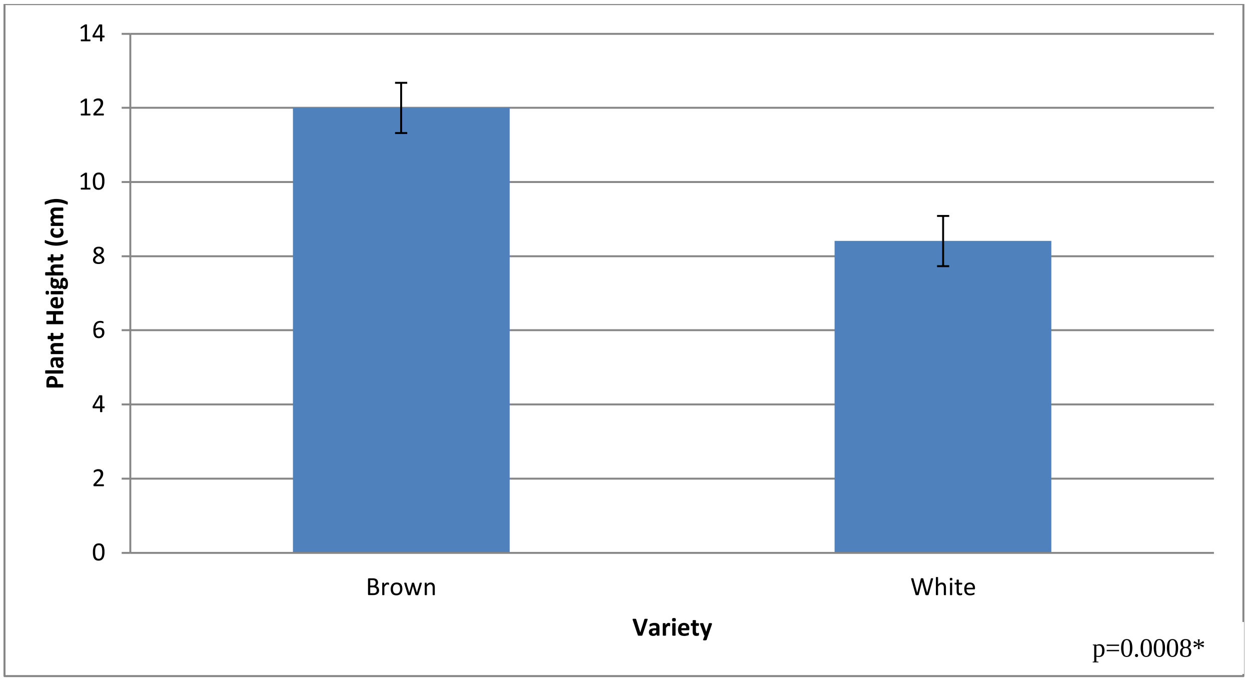
Figure 5. Monthly and historic average temperature (A) and precipitation (B) recorded in Steeles Tavern, VA during 2010 and 2011

3.3.2 Plant Height

In Blacksburg, plant height was not recorded in June of 2011 due to failure in stand establishment. Therefore, the plant height data for 2010 and 2011 were analyzed independently. There was a significant difference in plant height for planting date and variety in 2010 but there was no interaction between effects. The plant height for the brown and white varieties averaged over planting date was 12.00 cm and 8.41 cm, respectively (Figure 6A). The plant height averaged over varieties was 12.94 cm for the June planting compared to 7.47 cm for the July planting (Figure 6B). In 2011, there was no significant difference in varieties with the brown and white varieties averaging 29.35 cm and 26.06 cm, respectively (Figure 7).

At Steeles Tavern, there was a significant difference in plant height between year, planting date, and variety but there was no interaction between effects. Plants were significantly taller in 2011 (23.55 cm) compared to 2010 (19.20 cm) (Figure 8A). The June planting (22.70 cm) averaged significantly taller plant height than July (19.92 cm) (Figure 8B). Plant heights for the brown variety (22.61 cm) were greater than the white variety (20.03 cm) in 2010 and 2011 at Steeles Tavern (Figure 8C). There was also no correlation between plant height and grain yield.

A.



B.

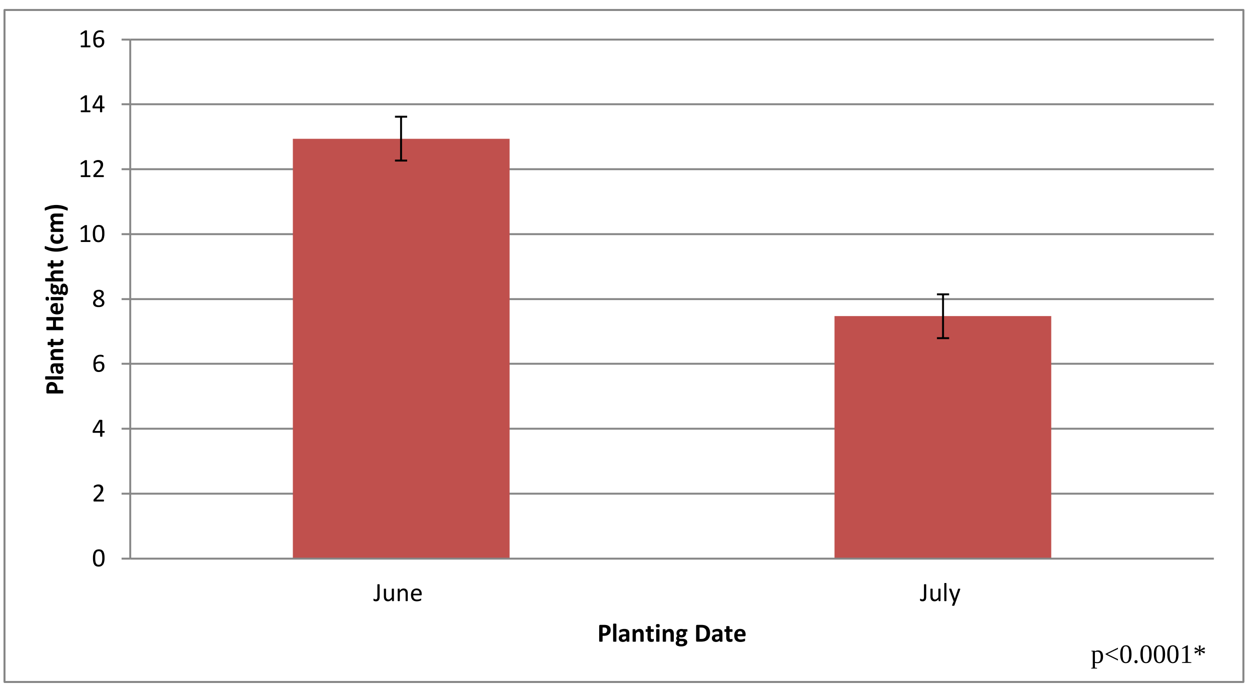


Figure 6. Average plant height and standard error bars by variety (A) and planting date (B) at Blacksburg in 2010

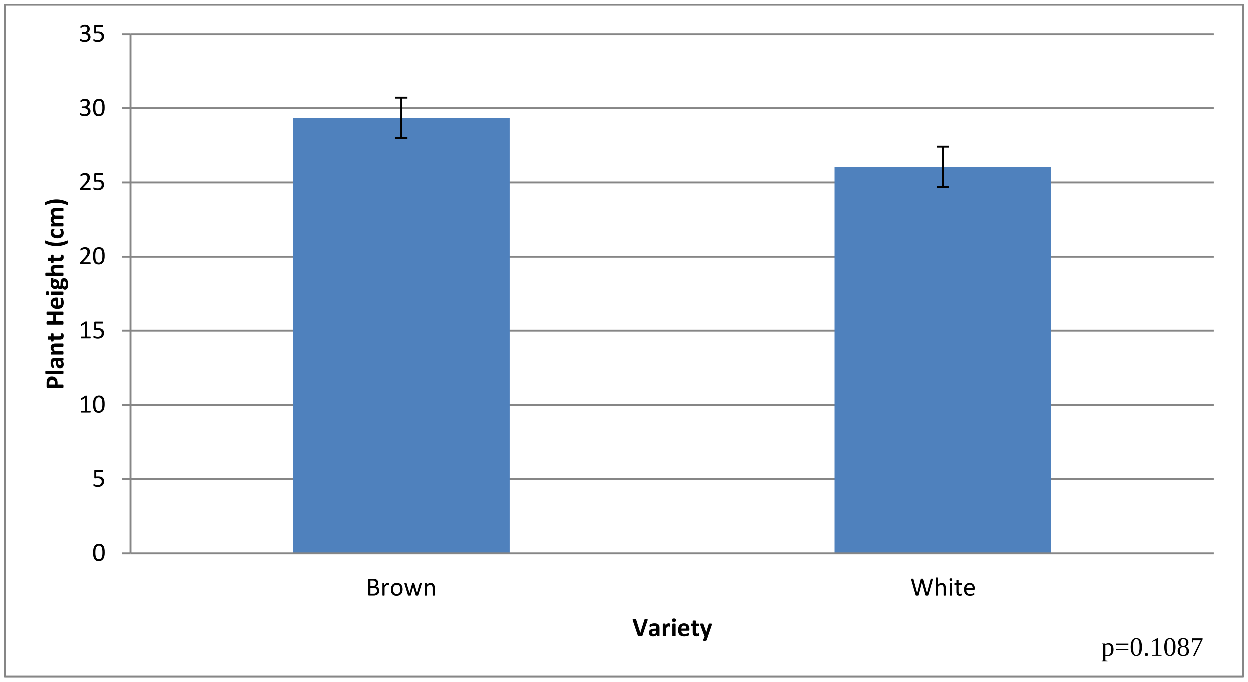
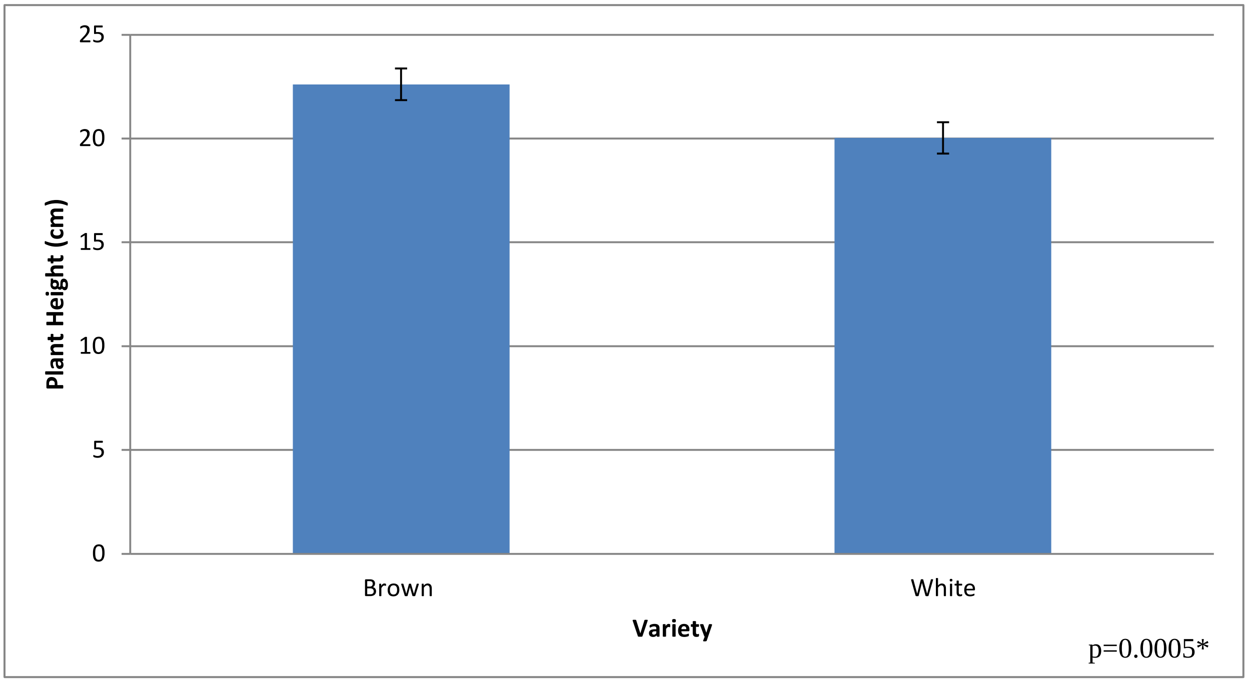
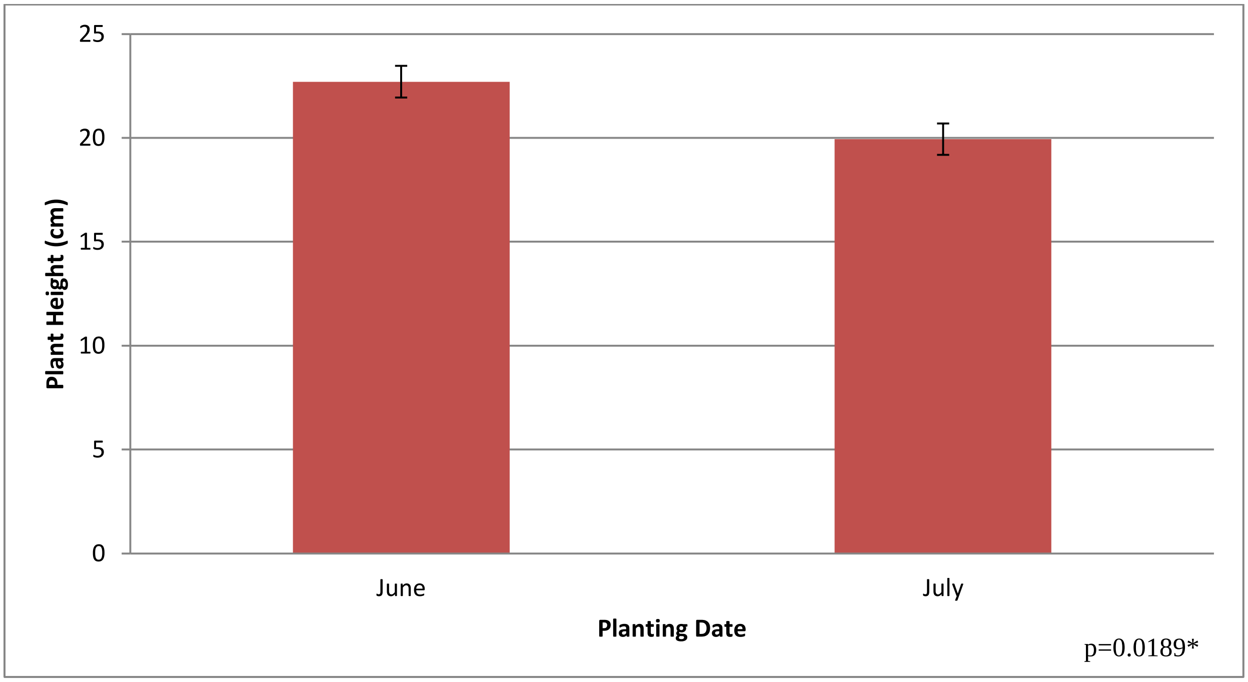


Figure 7. Average plant height and standard error bars by variety at Blacksburg in 2011

A.


25
20
15
10
5
0
Plant Height (cm)
Brown
White
Variety
p=0.0005*

B.


25
20
15
10
5
0
Plant Height (cm)
June
July
Planting Date
p=0.0189*

C.

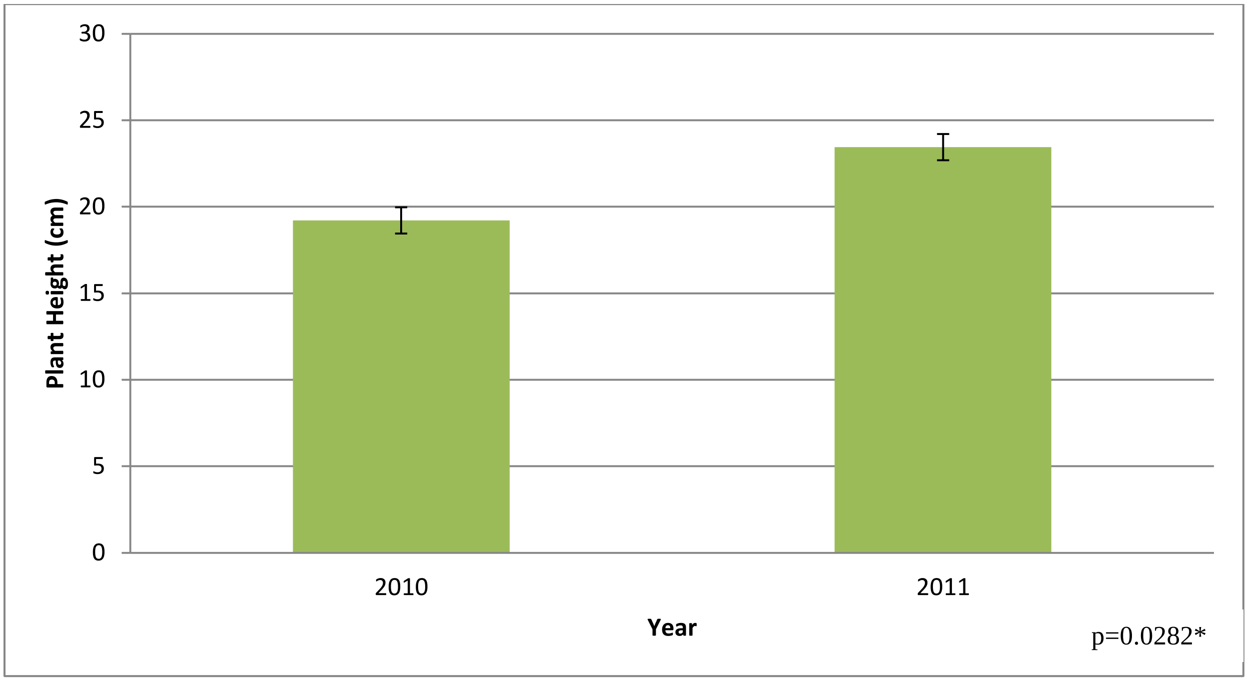


Figure 8. Average plant height and standard error bars by variety (A), planting date (B), and year (C) at Steeles Tavern

3.3.3 Straw Yield and Quality

In 2010, straw yield and quality were determined for the Steeles Tavern location. Straw data was not collected at Kentland due to failure in stand establishment. There was no significant difference in straw yield between planting date or variety (Figure 9). The straw yield, averaged over year and variety, was 2,560.3 kg ha^{-1}. In Ethiopia, Ketema reported the national average for teff straw production to yield a total 3,719.5 kg ha^{-1} annually compared to 2,603.6 kg ha^{-1} and 2,422.2 kg ha^{-1} for our brown and white teff straw samples, respectively.

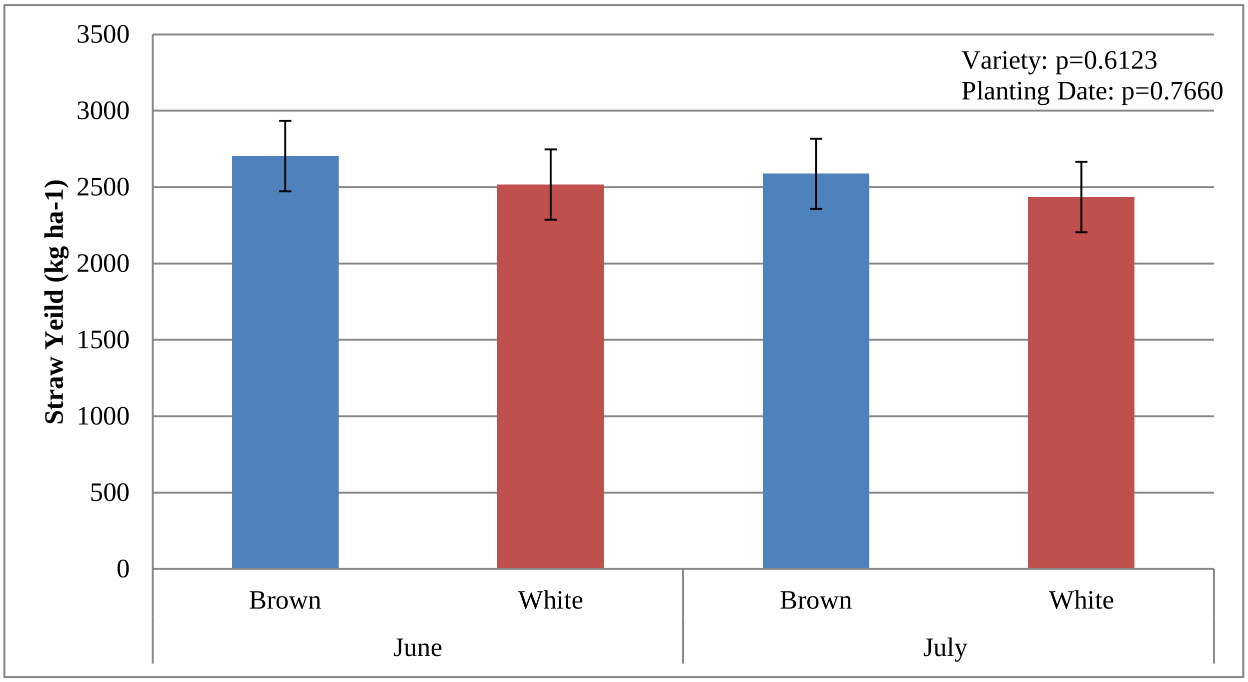
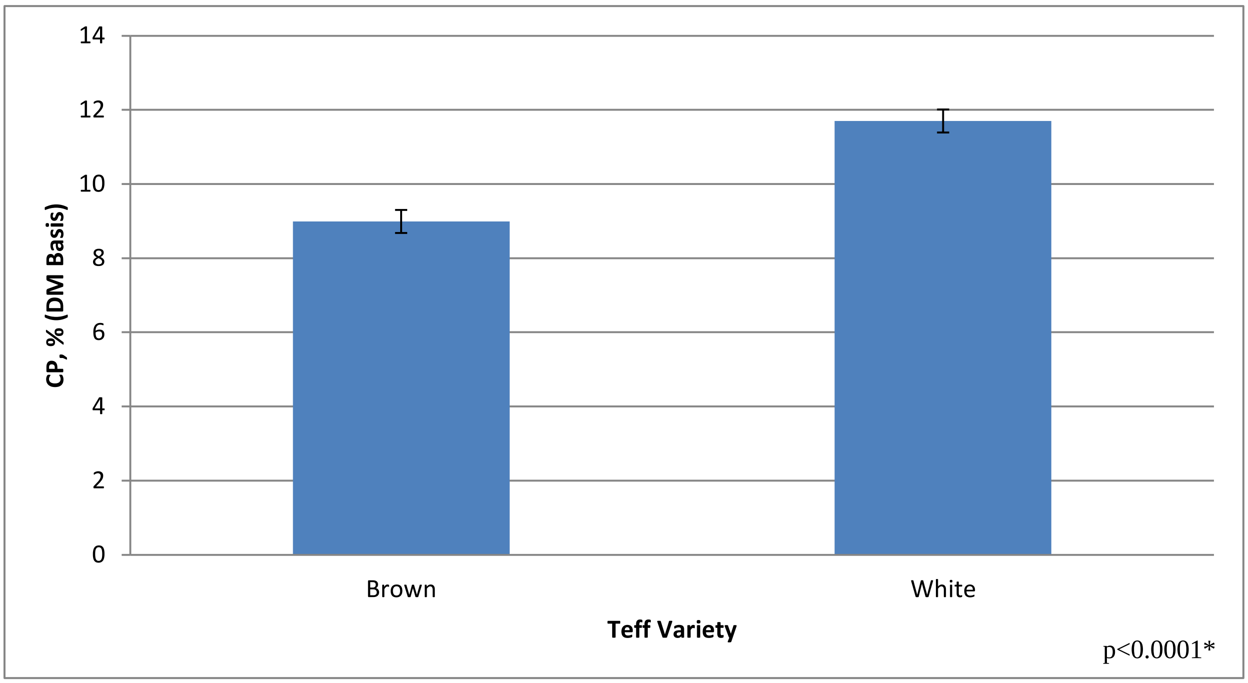


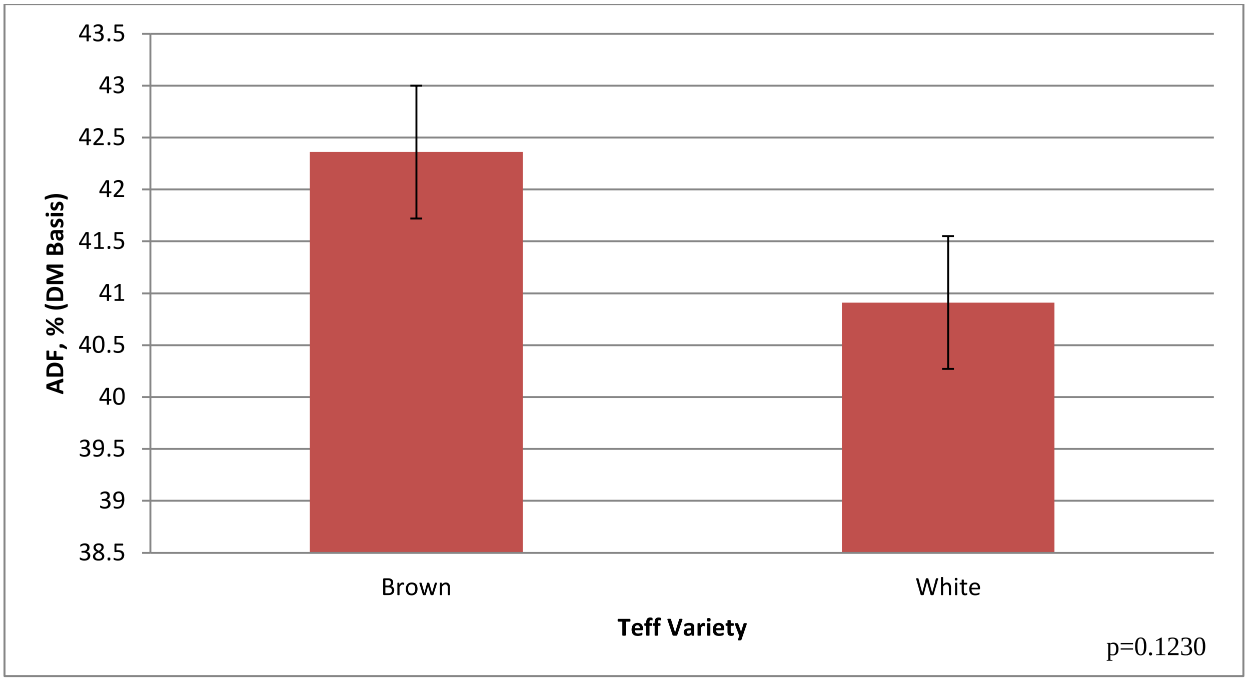
Figure 9. Straw yield after threshing (kg ha^{-1}) and standard error bars by planting date and variety at Steeles Tavern in 2010

There was no significant difference in nutritive value of teff straw between planting dates. Crude protein and ADF, however, differed among varieties. The CP values for the white variety teff straw were significantly higher than those of the brown variety with values averaging 11.7% and 9.0%, respectively (Figure 10a). This can be compared to the CP values for teff straw reported by Ketema (Ketema, 1997) which was 5.2%. The 9.0% CP values reported for the brown teff straw can satisfy the nutritional requirements of all livestock at the maintenance level while the 11.7% CP for the white teff straw can satisfy the nutritional requirements of animals above maintenance level (such as growing and milking animals) (Table 5). The ADF values were not significantly different between varieties (Figure 10b) but the NDF values for the brown teff straw were significantly higher than the white teff straw (Figure 10c). The ADF and NDF values for brown vs. white teff straw ranged from 42.4 and 40.9%, 71.5 and 67.9%, respectively (Table 5). The NDF value reported by Ketema (Ketema, 1997) was 72.6% which falls in close proximity to our findings. These values are within the acceptable level to satisfy the nutritional requirements of cattle at different production levels.

A.



B.



C.

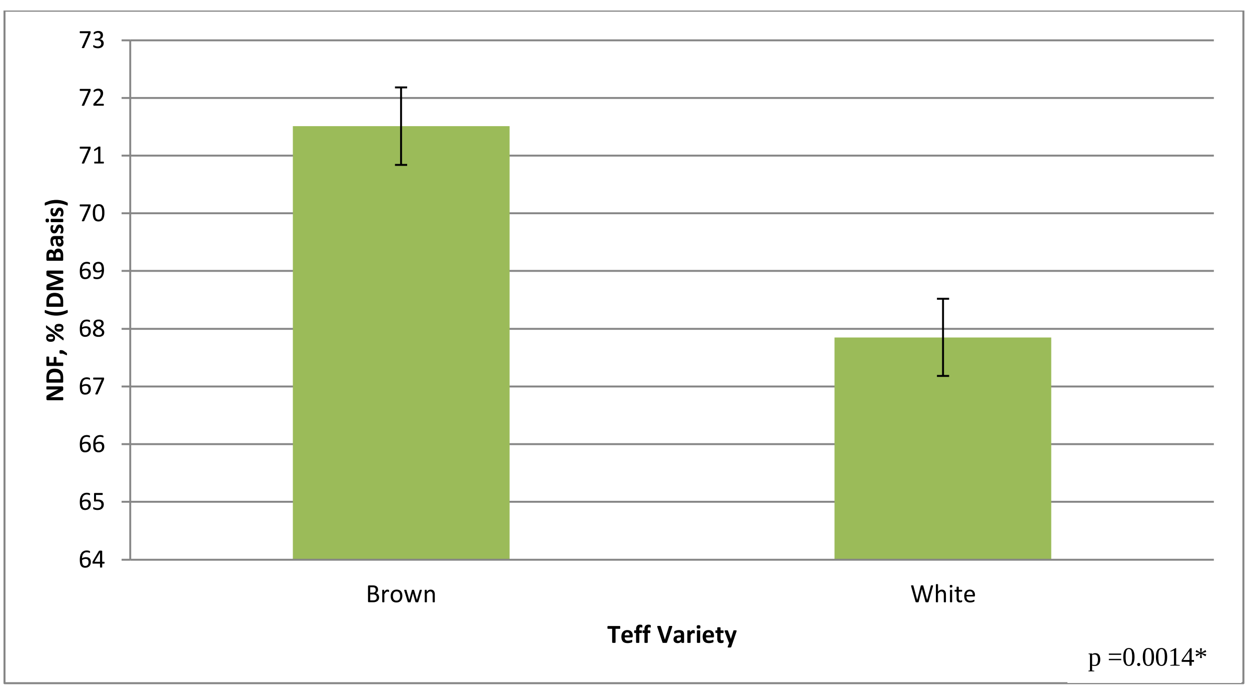


Figure 10. Crude protein (A), acid detergent fiber (B), neutral detergent fiber (C) levels and standard error bars by variety for 2010 Steeles Tavern

Table 5. Crude protein (CP), acid detergent fiber (ADF) and neutral detergent fiber (NDF) levels by teff variety for 2010 Steeles Tavern

Variety	**CP** (%DM)		**ADF** (%DM)		**NDF** (%DM)	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Brown	8.99[a]	0.31	42.36[a]	0.64	71.51[a]	0.67
White	11.7[b]	0.31	40.91[a]	0.64	67.85[b]	0.67

Letters indicates a significant difference between varieties for each column at $p \leq 0.05$

3.3.4 Grain Yield

While grain production for 2010 in Blacksburg largely failed due to both environmental and cultural practices such as planting depth and weed pressure, the growth and production of teff grain was relatively successful at the Steeles Tavern location. In 2010 for the Steeles Tavern location, grain yields were significantly higher for the brown variety compared to the white variety (Table 6). The yield difference between the brown and white teff varieties was 270 kg ha^{-1} (Table 6). While the brown variety yielded 367.0 kg ha^{-1}, the white variety only averaged 96.9 kg ha^{-1}. The yields in Virginia for both varieties are substantially lower than the grain yields reported by Ketema (1997) in Ethiopia with the national average for teff grain yield in 1997 totaling 907.2 kg ha^{-1}.

Planting date had no effect on grain production with the brown variety out yielding the white variety in both June and July (Figure 11). Since there was no significant difference in yield between planting dates for either variety, this suggests that there may be flexibility in the time of planting without significant reduction in grain yield. Figure 12 shows the different components of the seed. The threshed weight represents the total weight of the material after the seedhead has been through the thresher. It is the total weight of the seed, broken straw pieces and glumes. The trash weigh is the weight of the threshed weight minus the clean seed. As the data indicates, seed yield was greatly affected by a lack of means to easily thresh the seeds from the seedhead. The challenges of obtaining a clean seed are further complicated by the size of the seed. In fact, the majority of the yield loss can be attributed to the size and the color of the seed. There is relatively high yield loss due to the grain cleaners' inability to discriminate between the clean seed and the trash pieces. Also, unless the threshing equipment is totally air sealed, which is not possible, the seed can easily escape through any openings. The teff seed, especially the white variety, is difficult to distinguish from the trash and thus a significant amount of the seed could have been lost in the trash.

Table 6. Teff grain yield (kg ha^{-1}) by variety in 2010 at Steeles Tavern

Variety	**Grain Yield (kg ha^{-1})**	
	Mean	Standard Error
Brown	366.96[a]	28.85
White	96.89[b]	28.85

Letters indicates a significant difference between varieties for each column at P<0.0001*

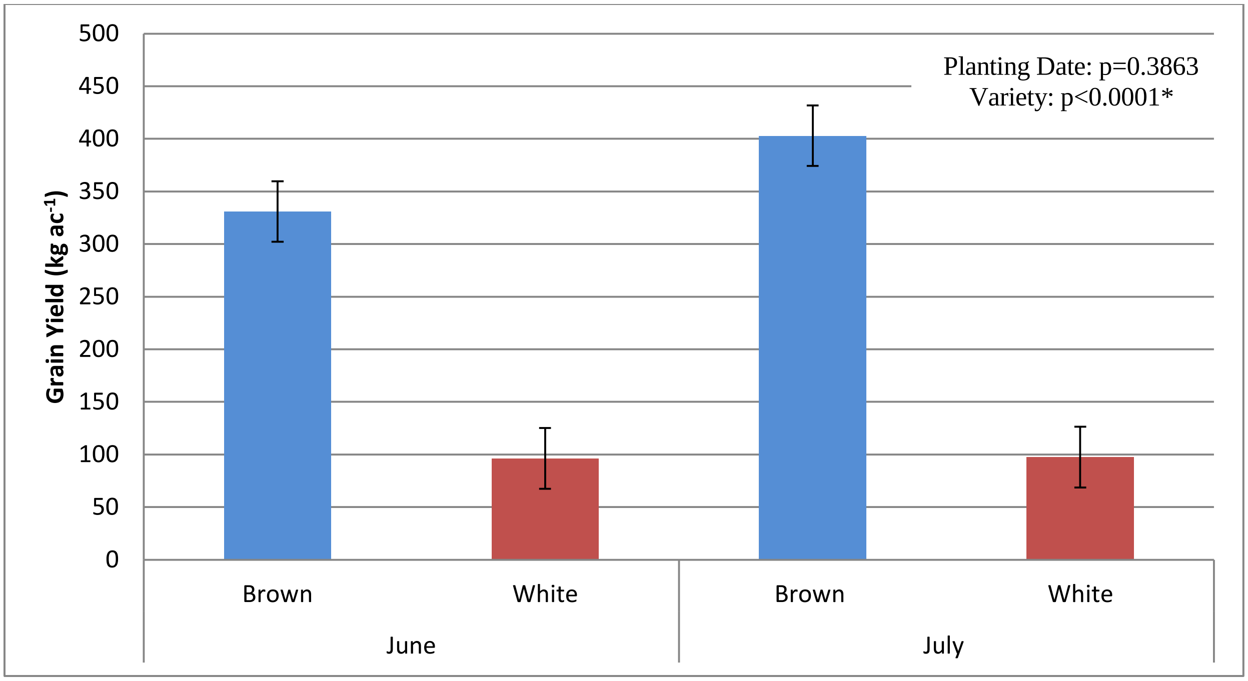


Figure 11. Grain yield and standard error bars for brown and white varieties at Steeles Tavern in 2010

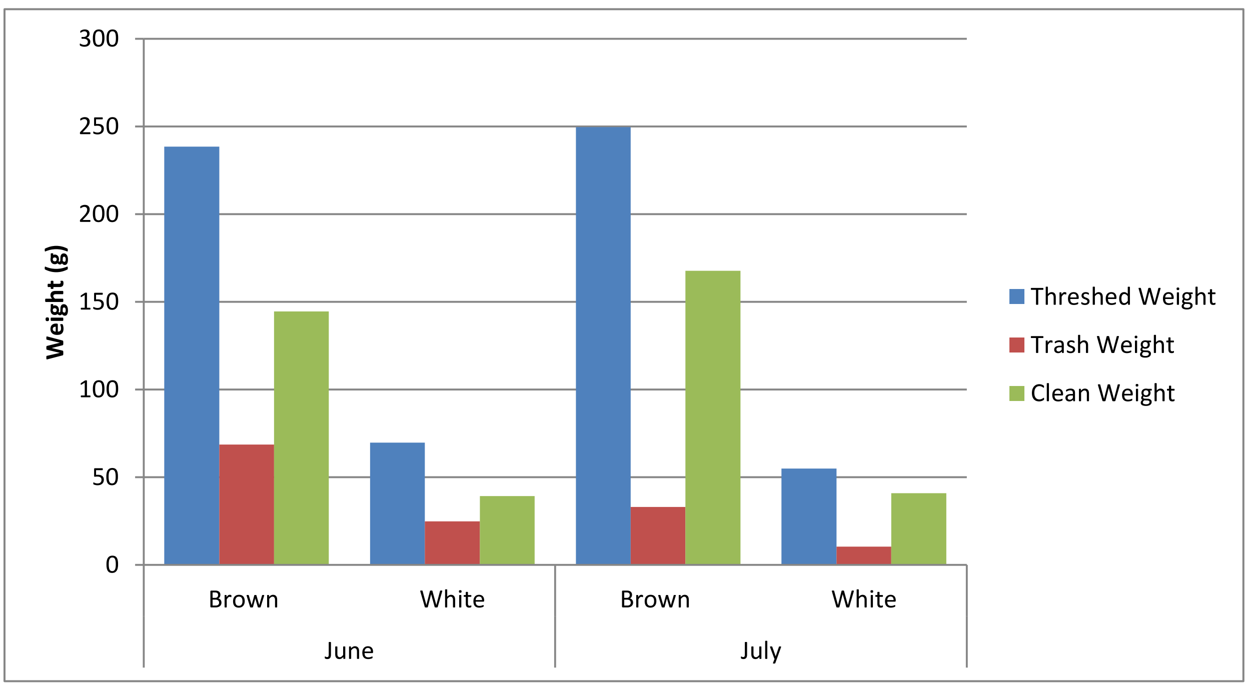


Figure 12. Weights of threshed material, trash removed in grain cleaning process, and clean grain at Steeles Tavern in 2010

3.4 Observations and Conclusion

3.4.1 Weed Control

There are currently no herbicides labeled for teff but we recommended 2-4,D for control of broadleaf weeds as a result of the success of weed control following application of this product. In 2010, we also used a trial post-emergence herbicide called Milestone to control broadleaf weeds and grass seedlings. Milestone was very effective in controlling weeds and partly explains the success of the plots at Steeles Tavern in 2010. In 2011 at Steeles Tavern, we did not use herbicide to control weeds so the plots were consequently highly invaded by broadleaf and grass weed species. The weed species out competed teff, shading out the teff seedlings and preventing successful establish and growth. At Kentland in 2010 and 2011, crabgrass invasion was dominant in most plots. Developing a post-emergence herbicide to control broadleaf and grass weeds is essential to successful teff grain production.

3.4.2 Planting Methods

There were several observations regarding planting methods of teff between locations and years. Due to the small seed size, planting too deep (> 5cm) prevents germination and emergence of teff. A firmer soil that has been tilled is most desirable for seedling emergence. In addition to increasing seed-to-soil contact, tilling is also important for weed control. In 2011 at Blacksburg, we planted teff no-till into the previous year's teff residuum. This was unsuccessful and not a single seedling emerged. On the other hand, teff was planted into wheat stubble at a farm in Dobson, North Carolina and was very successful. This is because wheat stubble stands upright and therefore does not prevent the small seed from achieving soil contact. Additionally, the wheat stubble also provided support for teff's flexible stems and shallow root and thus greatly reducing lodging.

In 2010 at Steeles Tavern, July plots were planted by broadcasting due to equipment problems. Although broadcasting is unsuitable for row crops, it may be noted that this method was successful on all plots. Lastly, although teff is known to be drought tolerant, this largely depends on the growth stage during which the stress occurs. Rainfall following initial planting is essential to germination and establishment. Irrigation may also be necessary following planting in the event of no rainfall or during grain development to maximize yield.

3.4.3 Teff Varieties

It is possible that a forage variety was planted rather than a grain type which would consequently affect grain yield. Between the brown and the white variety that we planted, the white variety more closely resembled a grain type compared to the brown variety. The brown variety had a much more open panicle compared to the white, which had a compact seed head. There was no significant difference in straw biomass between the brown or white variety but the white variety on average was shorter in plant height compared to the brown variety. A shorter plant would be more characteristic of a grain type. Even with differences in plant height, the brown variety yielded significantly more than the white variety. A breeding program may be necessary in order to achieve a variety shorter in plant height, with a more compact seed head.

3.4.4 Conclusion

Grain yield was significantly lower at the Steeles Tavern location compared to previously reported yields (averaging 97 kg ha^{-1} and 367 kg ha^{-1} for white and brown varieties, respectively). There was no significant difference in grain yield between June and July planting dates. This allows more flexibility in planting dates and increases the chance of a successful grain yield. Overall, our results demonstrate favorable environmental conditions for growing teff in Virginia provided the following cultural practices and management conditions are met:

1. Effective weed control
2. Successful establishment (control of seeding depth and seed-to-soil contact)
3. Higher yielding varieties (grain type) suitable to Virginia's growing conditions
4. More effective and reliable harvesting and threshing methods

Generally, it would be difficult to recommend large scale teff grain production in Virginia based on our two years of experience. Avoiding agronomic practices now known to be unsuccessful may produce better results for future research.

3.5 References

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Chapter 4

The Suitability of Teff Flour in Baked Products

Abstract

Teff, a gluten-free grain crop indigenous to Ethiopia, was added to various percentages of wheat flour to evaluate the ability of teff to produce a satisfactory baked product. Four types of baked products were tested: cakes, cookies, biscuits and bread with varying treatments of teff: control (100% wheat flour) and 10, 20, 30, 40 and 100% teff flour. Each treatment was replicated three times for each product. Physical tests were used to evaluate the quality of the final product. For the cake and bread products, only the volumes and colors of the samples were significantly different ($p \leq 0.05$) while no difference was found in texture, symmetry or uniformity among treatments for the cake samples ($p > 0.05$). The fracture strength of the cookie samples were not significantly different ($p > 0.05$) between treatments but the cookie spread and color was significantly greater at 40% and 100% teff flour ($p \leq 0.05$). There was a significant difference ($p \leq 0.05$) in biscuit height and color among teff treatments but no significant difference ($p > 0.05$) in texture, weight, or diameter. Overall, this study showed that teff flour is best suited for use in cookie and biscuit products. Teff's coarse, gluten-free flour is not recommended for use in cake and bread products.

4.1 Introduction

Teff is a grain crop endemic to Ethiopia where it has sustained people for many generations. Dating back to as early as before the birth of Christ, teff in Amharic literally means "the lost seed" because it is so small that if dropped, it is so easily lost. Teff is traditionally used to make a sour, spongy pancake-like bread called “injera” though it can also be combined with other flours to make baked products. It is the chemical composition of teff, however, that makes it such a desirable alternative to other cereal grains. High in essential amino acids, teff is higher in lysine that all other cereals except oats and rice (Ketema, 1997). Teff also has the highest iron content and more calcium, copper, zinc, aluminum, and barium than winter wheat, barley and sorghum (Ketema, 1997). Above all, teff is most notable for its high protein, gluten-free flour.

Qualitative differences in the types of flours are the result of gluten proteins which wheat contains and teff does not. Gluten proteins are essential to structure development of the baked product by providing a matrix in which the starch granules are embedded (Hui, 2006). As the temperature increases, gluten loses its water-binding ability which is transferred to the starch granules so that they can expand and swell to give the product its volume (Pomeranz, 1988). The suitability of a dough or gluten for a baked product can be determined through product testing.

On the other hand, proteins that are not gliadin or glutenin polypeptides are called soluble or non-gluten proteins and consist primarily of albumin and globulin proteins (Pomeranz, 1988). Albumin and globulin proteins are typically more nutritious than the proteins found in wheat due to higher concentrations of amino acids, like lysine (Pomeranz, 1988). The fractional composition of proteins in teff is as follows: 44.55% glutelins, 36.6% albumins, 11.8% prolamin and 6.7% globulins (Ketema, 1997). It is important to note that although teff has a high fraction of glutelin proteins, the proportion of the protein classes force them to function very differently than those of wheat (Tilley, 2011). Wheat prolamins and glutelins contain a specific amino acid sequence that elicits a response in individuals susceptible to gluten-intolerance (Tilley, 2011).

Like proteins, carbohydrates are also important to consider when examining the baking characteristics of particular flour. The most abundant carbohydrate in wheat is starch which is largely found in discrete, partially crystallized granules within the cells of the endosperm (Pomeranz, 1988). Milling practices that remove the bran and germ will therefore result in a flour that consists primarily of a starchy endosperm (Pomeranz, 1988). Starch undergoes a series of changes when heated in an aqueous solution that are essential to the functionality of baked products. These two transformations are called gelatinization and pasting during which the starch granules lose their crystalline structure and begin to swell (Pomeranz, 1988). Serving as a “temperature-triggered water sink”, the starch granules expand with increasing temperatures (Pomeranz, 1988). The ability of starch to undergo such changes is affected not only by water-availability but the presence of other ingredients (Pomeranz, 1988). Sugar and shortening are two ingredients, for example, that compete with starch for water and systems with high concentrations of sugar may delay starch gelatinization (Pomeranz, 1988).

Non-starch carbohydrates are known as dietary fiber because they cannot be digested by the human digestive track (Pomeranz, 1988). Dietary fibers are the main components of the plant cell wall and largely consist of cellulose and hemicellulose (Pomeranz, 1988). Of the non-cellulosic, non-starch polysaccharides, there are a complex group of materials collectively termed as pentosans. Absorbing up to 10x their weight in water, pentosans have been long thought to play an important role in the baking process though their exact relationship is not fully understood (Pomeranz, 1988). Divided into two major groups, water-soluble and water-insoluble pentosans, one-third to one-half of total pentosans are extractable in water (water-soluble) while the remaining fraction is water-insoluble, called hemicellulose (Pomeranz, 1988). The interactions of pentosans in the dough-mixing and baking process needs more research.

It is the unique taste and gluten-free flour that has drawn interest in the use of teff in baked products to the United States where more than 2 million people have been diagnosed with Celiac Disease (Fasano A, 2003). A condition that affects nutrient adsorption in the inner lining of the small intestine, patients with Celiac Disease cannot tolerate the gluten proteins that are present in wheat, barley, oats and rye (Fasano A, 2003). Achieving a diet that fulfills the daily nutrient requirements while avoiding products that contain gluten can be challenging and difficult. Finding alternative substitutes to the everyday diet that provides both nutrition and variety can become a task and while there are many alternative grains lacking in gluten, few offer the same nutritional sustenance as teff. Gluten-free flours include buckwheat, corn flour, cornmeal, guar gum, millet, and some oat varieties.

This study seeks to explore the suitability of teff flour for baked products that are acceptable to consumers. Since teff does not contain gluten, the protein responsible for providing lift in baked goods, baking with teff flour may present a challenge. Substituting teff with varying percentages of wheat flour may determine the amount of teff that can be added while still achieving a satisfactory product. The effect of teff in various baked products, evaluated based on physical tests, can determine the ability of teff to produce an acceptable baked food.

4.2 Materials and Methods

4.2.1 Experimental Design

Product samples were baked in a food lab in the Human Foods, Nutrition and Exercise Department at Virginia Tech. The baking characteristics were determined for four products: cakes, cookies, biscuits, and bread. All baked goods were evaluated according to methods approved by the American Association of Cereal Chemists (AACC International, 2009). Various quantities of teff flour (Bob's Red Mill Natural Foods, Inc; Milwaukie, OR) were mixed with wheat flour (cake flour: Reily Foods Co; New Orleans, LA; cookie and bread flour: (King Arthur Flour Co; Norwich, VT; biscuit flour: Big Spring Mill, Inc; Elliston, VA) to test the quality of the baked products. The treatments assigned to each product was a control (100% wheat flour), composites of 10, 20, 30 and 40% teff flour added to wheat flour, and finally one treatment with 100% teff flour (Table 7). Each treatment was replicated three times for each product. The experiment focused on one product at a time for an interval of two weeks. The order of treatments for each product was determined by arbitrarily selecting a treatment from a pool. The study was designed as a randomized block design. A total 72 samples (4 products * 6 treatments * 3 subsamples) were made within an 8 week period. Flavor, texture and color are the general attributes of cereal products. Though time did not permit sensory evaluations of each product, the physical characteristics of each treatment were determined for texture, color and volume.

Table 7. Treatments of teff and wheat flour for baked products

Treatment	**Treatment Composition**	
	Teff Flour (%)	**Wheat Flour (%)**
1	0	100
2	10	90
3	20	80
4	30	70
5	40	60
6	100	0

4.3 Physical Tests

4.3.1 Texture

Texture analysis of baked samples were measured using the Shimadzu EZ Test Texture Analyzer (Shimadzu, 1875). The objective of the texture measurements is to describe the deformation and response of each product. The texture analyzer consists of a flat platform with a probe positioned above the platform and attached to a movable arm. The arm moves up and down at a controlled speed with the sample placed on the platform and compressed to a specific distance using a probe that is suitable to the product under consideration. The equipment was set according to the product tested so the probe, travel distance and speed of travel vary among products. Finally, the test produces a force-time graph that displays the magnitude of resistance to deformation for each sample. All samples were allowed to cool for one half-hour before taking texture measurements.

Two texture readings were measured for each cake. Each cake was cut in half and a 2x2-inch square piece was cut from the center of each half for texture analysis. The probe, TA-9, was programmed to travel a distance of 10 mm at a speed of 100 mm sec^{-1} with a normal cycle. For cake samples containing 40% to 100% teff, the samples had to be stacked in order to get a texture reading due to the flatness of the baked product. For cookies, texture measurements were based on the fracture strength or the ease with which the probe cut through the cookie. Each batch yielded a total of six cookies. From each batch, three cookies were randomly selected for measurement of the fracture strength. The probe, TA-9, was programmed to travel a distance of 20 mm at a speed of 100 mm sec^{-1} with a normal cycle. The texture of the biscuit samples were measured on three randomly selected biscuits out of a total of eight biscuits per batch. The probe, TA-9, was programmed to travel a distance of 10 mm with a speed of 100 mm sec^{-1} with a normal cycle. Lastly, the texture of the bread samples was measured on both the slice and loaf of each half of a total bread loaf. Each slice was taken from the center of each half of the loaf with each sample 30 mm in thickness. Loaf readings were taken with a probe programmed to travel a distance of 20 mm with a speed of 100 mm sec^{-1} with a normal cycle. The slice readings were taken at a distance of 10 mm and a speed of 100 mm sec^{-1}.

4.3.2 Color

The color of each baked sample was measured using the Minolta Colorimeter CR300 Series (Mahwah, NJ). Hunter L, a and b values were measured where the L*a*b* values represent a color space created for measuring the object of a color (Table 8). L* measures the lightness of a color whereas a* and b* are equal to the chromaticity, indicating the direction of the color coordinate. The L-value differentiates the varying levels of black (L=0) and white (L=100). The “a” and “b” values are determined by the value. For example, when the “a” value is positive (+), then the color is red while a negative value (-) “a” value suggests that the color is green. When the “b” value is positive (+) then the color is yellow while a negative (-) “b” value suggests that the color is blue (Table 8).

Color readings were taken on the crust of each half on the cake, as well as on the crumb of each half of the cake. For cookies, three were randomly selected for color readings and measurements were taken on the surface of each cookie. Color readings were taken on the crumb and crust of three randomly selected biscuits. Finally, color readings were taken on the crumb and crust of each half of a loaf of bread. Measurements were average for each batch of samples.

Table 8. Minolta (L, a and b) color values

Color	Minolta Colorimeter CR-300 Series (L, a, and b values)
Red	is a positive (+) a
Green	is a negative (-) a
Yellow	is a positive (+) b
Blue	is a negative (-) b
Black	L=0
White	L=100

4.3.3 Volume, Symmetry and Uniformity

Volume, symmetry and uniformity were determined for each cake using the layer-cake measuring template. Each cake was cut in half and each half was then placed along the edge of a flat surface. Using a layer cake measuring chart, contour and symmetry of the baked caked is described my measuring the height, center, and two points three-fifths of the distance from the center to the edge (Whitaker, 2004). The calculated values are compared to a control cake to determine how combinations of teff flour with wheat flour affect such physical attributes of the layer cake (Whitaker, 2004). Positive values of symmetry indicate a peaked cake whereas negative values indicate a collapsed center (Whitaker, 2004). Cake uniformity is measured by the difference between the heights of the two points measured at three-fifths the distance from the center to the edge and should be equal to zero (Whitaker, 2004). Ideally, the two heights should be equivalent indicating a dome-shaped contour (Whitaker, 2004). This method only proposes an index for volume and needs to be compared to the control volume. It does not produce quantitative data for cake volumes (Whitaker, 2004). The contour of a high-quality, high-ratio layer cake should produce a symmetrical dome (Whitaker, 2004). The quality of the resulting cake, as well as symmetry, uniformity, and volume, can be significantly altered by changes in flour treatments (Whitaker, 2004).

The American Association of Cereal Chemists has approved two methods of volume measurement for breads and cakes: rapeseed displacement method and the use of a template for cross-sectional areas (Whitaker, 2004). The rapeseed displacement method determines the volume of oddly shaped products by measuring the amount of rapeseeds that the object displaces. This was therefore the method used for loaves prepared in this study. One problem with this method is the possibility that the rapeseeds crush the product, skewing the volume. This is more of a problem for cakes rather than breads.

4.3.4 Cookie Spread Factor

Cookie quality is determined (in six cookies) by width (W), thickness (T), and W/T ratio (cookie spread factor). After cooling for 30 minutes, the cookies were laid edge to edge and measured by width. The cookies were then rotated 90° and re-measured to obtain the average width (W) of six cookies in mm. The thickness was determined next by stacking the cookies one on top of another and measuring the total thickness for all six cookies. The cookies were then re-stacked in different order and re-measured to get the average thickness (T) of six cookies in mm. Measurements were rounded to nearest ½ mm for width and thickness. Width and thickness were divided by six to obtain the average W (as-is) and T (as-is) per cookie. Using a correction factor (CF), adjusted W, T, and W/T ratio (spread factor) were calculated as follows:

(1) Width (W) divided by thickness (T) is W/T ratio (as-is)

(2) W/T (as-is) x CF = adjusted W/T. See Note 9, Table II.

(3) Adjusted W/T x 10 = spread factor

(4) W (as-is) x CF = adjusted W. See Note 9, Table III.

(5) T (as-is) x CF = adjusted T. See Note 9, Table IV.

Width is recommended as the most sensitive and reliable estimate of flour quality. Width and, in some cases, thickness of cookies are better estimates of flour quality than in W/T ratio (spread factor) because it is a ratio of two measured parameters. Both width and thickness could vary such that several widths and thicknesses could give the same spread factor. Since volume is not a desirable characteristic of cookie quality, volume measurements were not taken on the cookies.

4.3.5 Biscuit Thickness and Spread

Biscuit volume was determined by measuring the height, diameter, and weight of each baked biscuit. After allowing the biscuit to cool for 30 minutes, the weight of each of the eight biscuits were measured individually and then average to obtain a total value. The diameter of each biscuit was then measured, turning each biscuit three times to make three diameter readings per biscuit. The mean of the three measurements is then determined to obtain an average diameter per biscuit. Lastly, the height of each biscuit is measured at the top center and the total height was reported for all height biscuits.

4.3.6 Statistical Analysis

Data was analyzed using the JMP (JMP, 2010) statistical software. The tests for color, texture, volume, symmetry, uniformity, height, weight and diameter were all analyzed by a completely randomized design using analysis of variance (ANOVA). The mean values recorded for each test were compared using a one-way analysis of variance (ANOVA). Error bars and included in each figure to indicate the amount of deviation from the mean for each test. Significance was determined using a p-value of less than or equal to 0.05 ($p \leq 0.05$).

4.4 Results and Discussion

4.4.1 Chemical Composition

Tables 9 and 10 show the chemical composition of teff in comparison with other cereal grains. Bob's Red Mill Teff Flour was analyzed as control flour since this was the flour we used in the baked products. Additionally, the brown and white teff samples obtained from our field experiments were analyzed.

4.4.2 Amino Acid Profile

The brown and white varieties grown in Virginia are higher in glutamic acid and proline compared to commercial teff flour though still considerably less than wheat flour (Table 9). Our brown and white teff varieties are higher than commercial teff flour in all essential amino acids. The white teff variety was much higher than both the brown variety and the store-bought teff flour. The amino acid composition of teff flours were not consistent with previously published data by Ketema et al. (1997) and our values were frequently lower than those previously reported. The lysine content of teff flour published by the National Agricultural Library is more consistent with Ketema's (1997) findings than our samples. Ketema et al. (1997) indicated that teff was higher in all essential amino acids except oats and rice but our data did not support that finding. Inconsistencies may be attributed to differences in variety or growing conditions.

Table 9. Amino acid composition (g/100 g) of teff flour compared to other cereal grains

Amino Acid Profile	Control Teff [a]	Brown Teff [a]	White Teff [a]	Barley [b]	Corn [b]	Oats [b]	Whole Wheat [b]	Wheat [b]	Teff [c]
Aspartic Acid	0.61	0.68	0.79	0.62	0.66	1.45	0.72	0.42	0.82
Threonine	0.37	0.46	0.51	0.34	0.35	0.58	0.37	0.27	0.51
Serine	0.40	0.49	0.54	0.42	0.45	0.75	0.62	0.49	0.62
Glutamic Acid	2.34	3.12	3.40	2.59	1.77	3.71	4.33	3.33	3.35
Proline	0.49	0.62	0.69	1.18	0.82	0.93	2.08	1.15	0.66
Glycine	0.32	0.35	0.39	0.36	0.39	0.84	0.57	0.36	0.48
Alanine	0.51	0.61	0.70	0.39	0.71	0.88	0.49	0.32	0.75
Valine	0.49	0.62	0.69	0.49	0.48	0.94	0.56	0.40	0.69
Cystine				0.22	0.17	0.41	0.28	0.21	0.24
Methionine				0.19	0.20	0.31	0.23	0.18	0.43
Isoleucine	0.38	0.48	0.54	0.36	0.34	0.69	0.44	0.34	0.50
Leucine	0.76	0.96	1.07	0.67	1.16	1.28	0.90	0.68	1.07
Tyrosine	0.42	0.53	0.58	0.28	0.38	0.57	0.28	0.30	0.46
Phenylalanine	0.52	0.66	0.75	0.56	0.46	0.90	0.68	0.50	0.70
Lysine	0.29	0.29	0.35	0.37	0.27	0.70	0.36	0.22	0.38
Histidine	0.23	0.26	0.29	0.22	0.29	0.41	0.36	0.22	0.30
Arginine	0.45	0.47	0.51	0.50	0.47	1.19	0.65	0.40	0.52

Sources: [a](Medallion Labs 2012), samples produced in Virginia, [b](Nutrient Data Laboratory, 2005), [c](National Agricultural Library, 2011)

4.4.3 Nutrient Profile

The nutrient profile of teff compared to wheat, maize and rice flour is listed in Table 10. Teff was comparable to wheat flour in total carbohydrates but much lower in calorie content compared to all other cereal grains. Teff had the highest sugar content and was higher in dietary fiber than all other cereals except barley. Our data supported previous findings that teff is higher in iron content than all other cereals (Ketema, 1997). Teff was also notably high in calcium.

Table 10. Nutrient profile (per 100g) of teff, wheat, maize and rice flour

Analysis	Control Teff [a]	Brown Teff [a]	White Teff [a]	Barley [b]	Corn [b]	Oats [b]	Rice [b]	Wheat [b]	Teff [c]
Moisture (2-stage) (g)	9.25	8.80	8.20	10.09	10.37	8.22	11.89	10.59	8.82
Ash (As Is) (g)	2.77	2.04	2.40	1.11	1.20	1.72	0.61	4.33	2.37
Protein N x 5.7 (As Is) (g)	10.77	12.87	14.19						
Fat by GC:	-	-	-	-	-	-	-	-	-
Fat (Total) (As Is) (g)	3.05	2.73	2.87	1.16	4.74	6.90	1.42	0.97	2.38
Fat (Saturated) (As Is) (g)	0.75	0.73	0.79	0.24	0.67	1.22	0.39	0.15	0.45
Trans Fatty Acids (g)	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fat (Polyunsaturated) (g)	1.54	1.34	1.36	0.56	2.16	2.54	0.38	0.41	1.07
Fat (Monounsaturated) (g)	0.75	0.66	0.72	0.15	1.25	2.178	0.44	0.09	0.59
Carbohydrates (g)	74.17	73.57	72.34	77.72	74.26	66.27	80.13	74.22	73.13
Calories	330.84	333.24	335.81	3,530	3,650	3,890	3,660	3,540	3,670
Calories from Fat	27.41	24.53	25.81						
Total Dietary Fiber (As Is) (g)	11.86	10.79	11.23	15.60	7.30	10.6	2.40	2.70	8.00
Fiber, Soluble (As Is) (g)	2.78	1.53	2.19						
Fiber, Insoluble (As Is) (g)	9.08	9.26	9.03						
Total Sugar (g)	3.30	1.60	4.20	0.80	0.64		0.12	0.22	1.84
Cholesterol (mg)	0.38	0.41	0.51	0	0	0	0	0	
Vitamin A (Iu)	ND	ND	ND	22	214	0	0	0	9
Ascorbic Acid (mg)	ND	ND	ND	0	0	0	0	0	
Calcium (mg)	204	189	182	29	7	54	10	338	180
Iron (mg)	15.10	12.80	18.90	2.50	2.71	4.72	0.35	4.67	7.63
Sodium (mg)	6	ND	ND	9	35	2	0	1270	12

Sources: [a](Medallion Labs 2012), Samples produced in Virginia, [b](Nutrient Data Laboratory, 2005), [c](National Agricultural Library, 2011)

4.4.4 Cake Product

Texture

The texture of the cake samples was determined by measuring their resistance to deformation (Figure 13). To produce a soft and tender cake product, flour protein content should be between 7 – 9% (Pomeranz, 1975). It is said that protein content can affect crumb firmness so flours with high protein may result in a firmer cake. The protein content of Bob's Red Mill teff flour is 10.77% with samples grown in Virginia ranging from 12.87 to 14.19% for brown and white teff, respectively. The protein content of teff flour therefore exceeds the recommended percent. This resulted in a firmer texture and greater compression strength for cake samples baked with higher percentages of teff flour, though there was no significant difference among treatments (Figure14).

Figure 13. Evaluating the texture of cake samples by compression strength

Milling practices for cake flour are designed to remove the germ and bran to produce flour consisting primarily of starchy endosperm. Control cake samples containing 100% wheat flour and thus high in starch resulted in a soft and light cake crumb that was lower in compression strength. The total carbohydrate content in teff flour ranges from 72.34 – 74.17% though the percent that is starch is unknown. The starch content of wheat ranges from 63 – 72% (Pomeranz, 1975). Gelatinization and swelling of the starch granules is important to the development of a texturally desirable product. Teff flour is high in bran and germ so samples containing higher percentages of teff resulted in a coarser, grainier product. Tenderness and softness are desirable qualities in a cake product and additions of teff flour reduced these characteristics. Still, though increased teff content produced a moist and grainy final product, the compression strength was not significantly affected by the treatments.

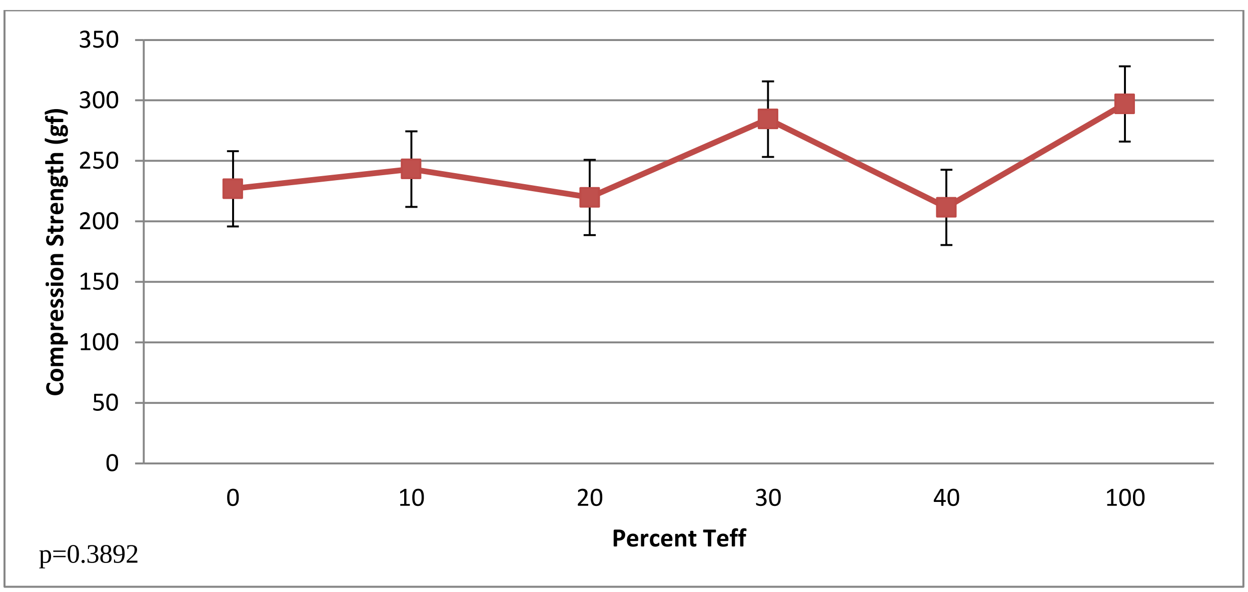


Figure 14. Compression strength (gf) of cake samples by percent teff

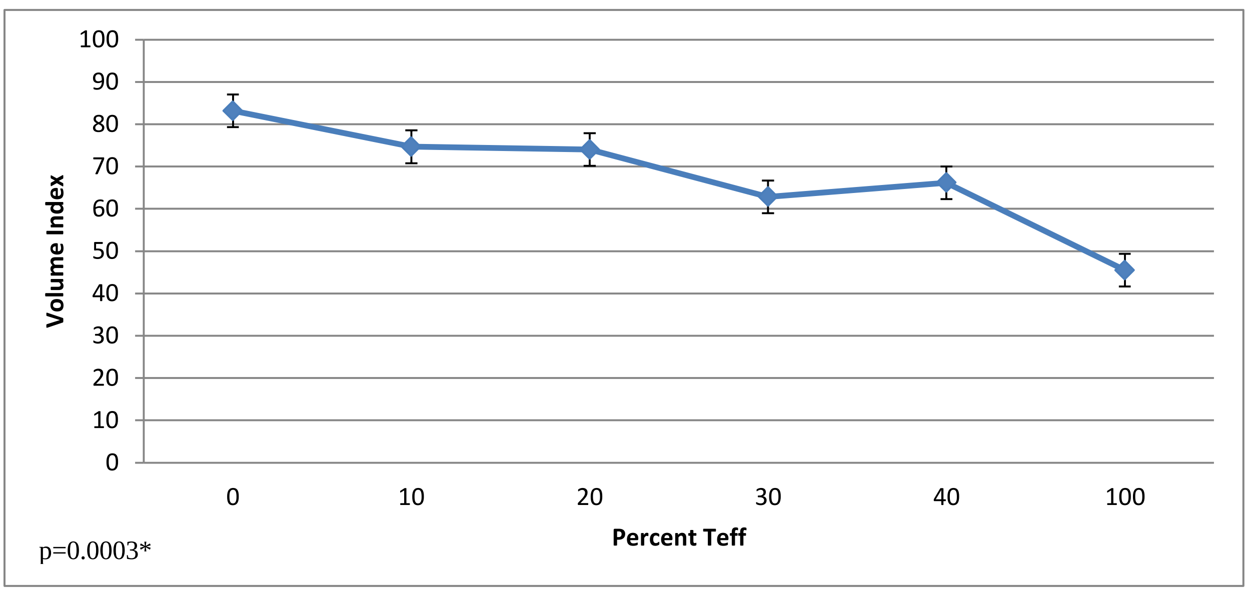
Volume, Symmetry and Uniformity

The volume of the cake samples was most affected by protein quality. Essential to structure development of the baked product, gluten is responsible for forming a matrix in which the starch can embed. Due to the chemical composition of teff flour, the absence of gluten prevents this structural matrix from developing (Figure 15). The volume of the cake samples was therefore significantly reduced with increasing percentages of teff (Figure 16a). The mean volumes for teff treatments are reported in Table 11 and treatment volumes that are significantly different from one another are indicated by a different letter.

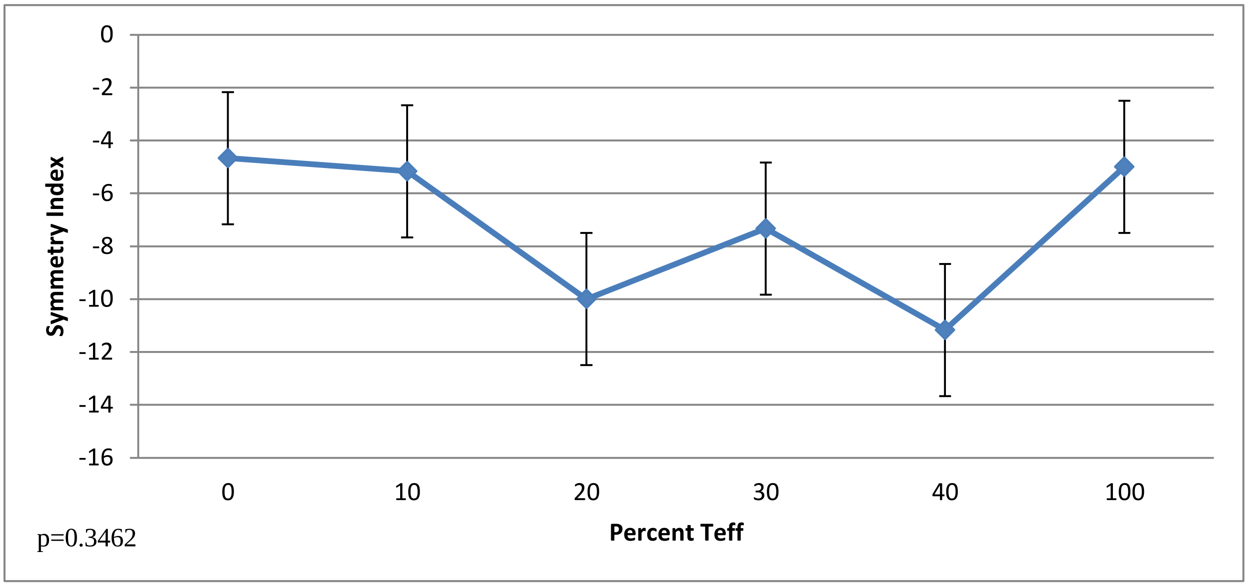
Figure 15. Absence of gluten proteins prevents structure development in cake samples with use of 100% teff flour

Flour treatment is also a factor that is believed to affect the crumb of the final product. The chloride treatment of cake flour is reported to affect cake volume and symmetry, as well as the stickiness of the crumb (Whitaker and Barringer, 2005). For example, cakes baked with untreated flour did not achieve a dome-shaped contour and was flatter and sometimes dipped in the center compared to cakes baked with chlorinated flour (Whitaker, 2004). Since teff flour has not received a bleaching treatment, it does not have the added benefits that the treated wheat flour does. Though there were significant differences in the volume of the final products, it is believed to be attributed more to protein quality rather than flour treatments. It is possible that the wheat flour treatment affected the symmetry of cakes baked with higher percentages of teff flour but no significant differences were observed in the symmetry of the final product (Figure 16b). There were no significant differences in uniformity among treatments either (Figure 16c). The mean values for volume, symmetry and uniformity among different treatments are reported in Table 11.

A.



B.



C.

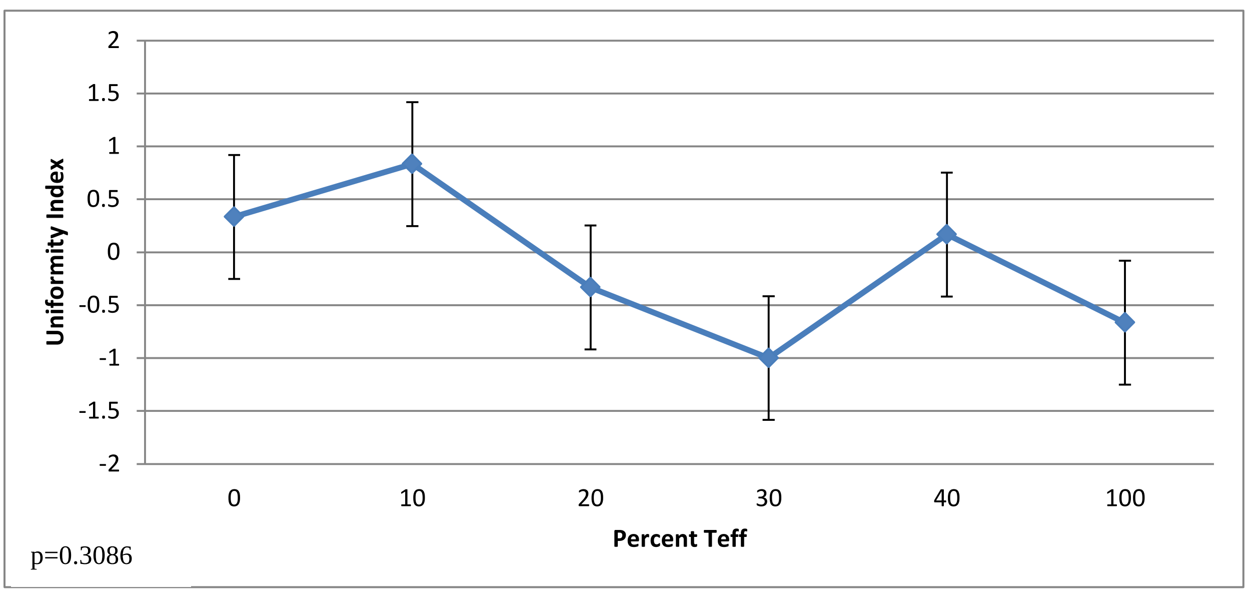


Figure 16. Mean volume (A), symmetry (B) and uniformity (B) index of cake samples by percent teff

Table 11. Mean volume, symmetry and uniformity index of cake samples by percent teff

Percent Teff	Mean Volume	Mean Symmetry	Mean Uniformity
0	83.17[a]	-4.67[a]	0.33[a]
10	74.67[ab]	-5.17[a]	0.83[a]
20	74.00[ab]	-10.00[a]	-0.33[a]
30	62.83[bc]	-7.33[a]	-1.00[a]
40	66.17[ab]	-11.17[a]	0.17[a]
100	45.50[c]	-5.00[a]	-0.67[a]

*Levels not connected by the same letter are significantly different at $p \leq 0.05$

Color

Generally, a yellow crumb is characteristic of a white cake. The crumb and crust color of the cake samples were measured and Hunter L, a and b-values were reported since these are the values commonly used to evaluate the color of baked goods. The values indicate that the color of the crumb and crust using 100% wheat flour were lighter in color (higher L-values) and more yellow (higher (+) b-values) than cake's baked with higher percentages of teff flour (Figure 17a and 17c). A darker cake was expected since teff is whole grain containing the bran and germ. Teff also contains a higher ash content compared to wheat flour which produces a darker, greyer color. Treating the teff flour with chlorination is one way to produce a cake baked with teff that is lighter in color. The Hunter a-values for the crumb and crust are inconsistent with the a-values for the crust increasing while a-values for the crumb decrease (Figure 17b). The significance of differences in Hunter L, a and b-values among treatments for the crumb and crust are reported in Tables 12a and 12b.

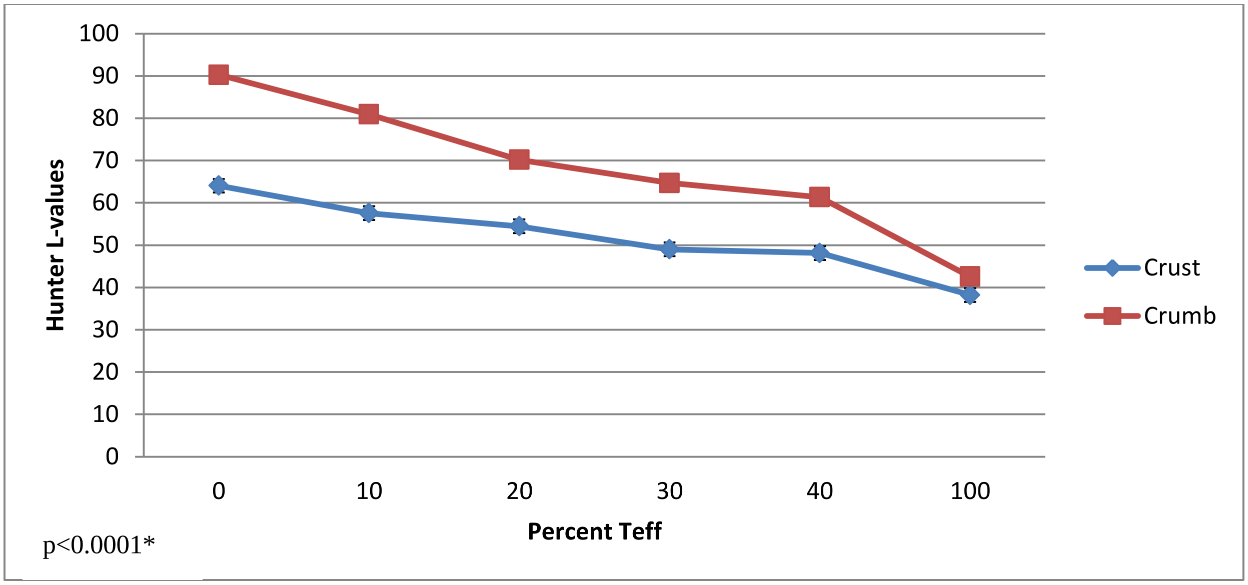


Figure 17a. Changes in Hunter L-values* of cake samples for different percentages of teff
*L = 0 = black; L = 100 = white

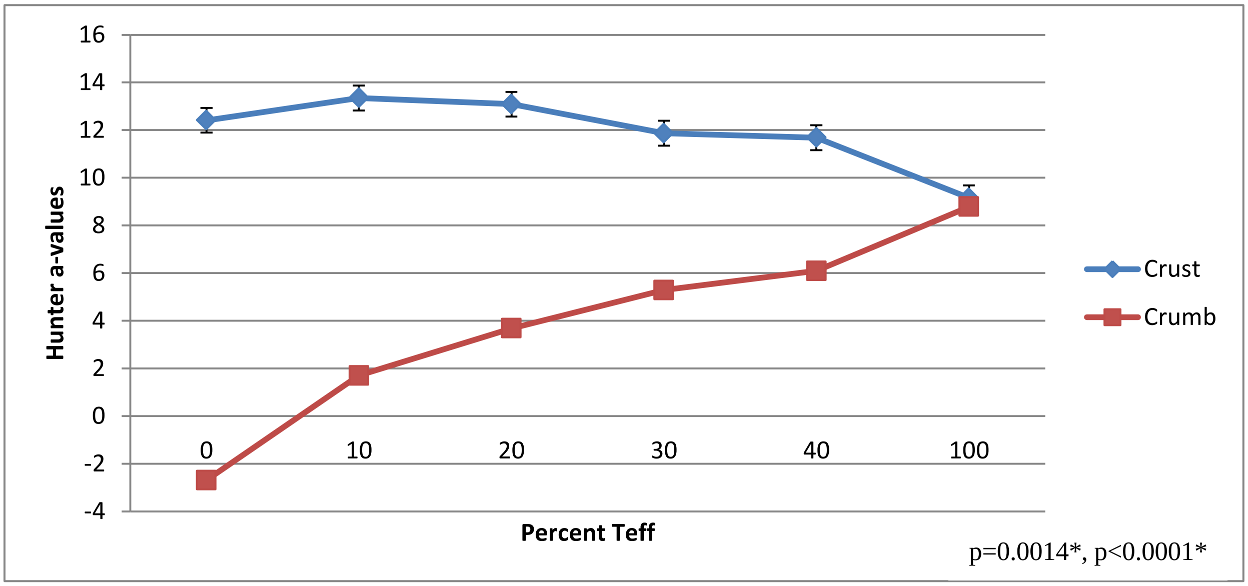


Figure 17b. Changes in Hunter a-values* of cake samples for different percentages of teff
* +a = red; -a = green

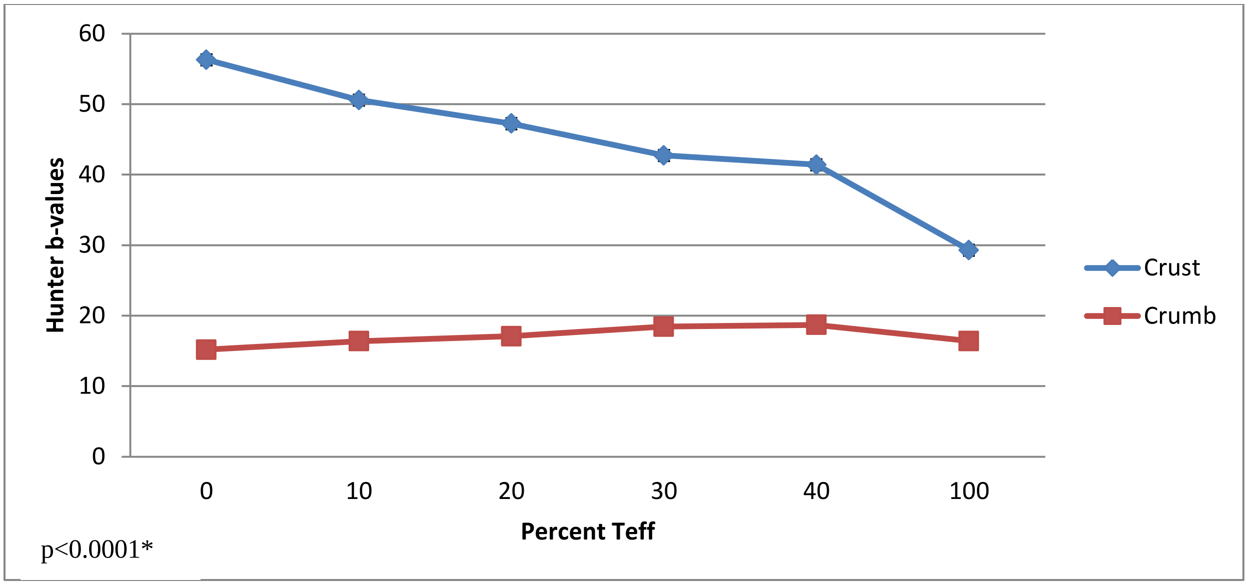


Figure 17c. The changes in Hunter b-values* of cake samples for different percentages of teff
* +b = yellow; -b = blue

Table 12a. Mean crust color (Hunter L, a and b-values) of cake samples for all percentages of teff

Percent Teff	Hunter L-value[1]	Hunter a-value[2]	Hunter b-value[3]
0	64.05[a]	12.41[a]	41.11[a]
10	57.56[ab]	13.35[a]	34.20[b]
20	54.45[bc]	13.09[a]	30.15[c]
30	49.00[c]	11.87[a]	24.28[d]
40	48.13[c]	11.68[a]	22.72[d]
100	38.23[d]	9.16[b]	12.88[e]

*Levels not connected by the same letter are significantly different at $p \leq 0.05$
[1] L = 0 = black; L = 100 = white
[2] +a = red; -a = green
[3] +b = yellow; -b = blue

Table 12b. Mean crumb color (Hunter L, a and b-values) of cake samples for all percentages of teff

Percent Teff	Hunter L-value[1]	Hunter a-value[2]	Hunter b-value[3]
0	90.23[a]	-2.69[a]	15.18[a]
10	80.94[b]	1.70[b]	16.37[a]
20	70.16[c]	3.68[c]	17.08[b]
30	64.68[cd]	5.28[d]	18.44[bc]
40	61.33[d]	6.09[e]	18.68[bc]
100	42.57[e]	8.78[f]	16.40[c]

*Levels not connected by the same letter are significantly different at $p \leq 0.05$
[1] L = 0 = black; L = 100 = white
[2] +a = red; -a = green
[3] +b = yellow; -b = blue

4.4.5 Cookie Product

Texture

A cracking pattern on the cookies was more prominent in cookies with higher percentages of teff flour. The cracking pattern can be explained by a rapid loss in moisture from the surface of the cookie during baking (Hoseney, 1994). The hot air in the oven as a great capacity for holding water and as water is lost from the surface of the cookie, it is replaced by moisture from the cookie’s interior (Hoseney, 1994). As moisture is pulled from the interior to the exterior of the cookie, the sugar becomes more concentrated (Hoseney, 1994). Sugar has a tendency to crystallize and as the sugar crystallizes, it no longer has the capacity to hold the water that gives the cookie a moist and moldable surface (Hoseney, 1994). The surface of the cookie therefore dries and cracks as the cookie expands (Hoseney, 1994). This phenomenon was more evident in cookies with 30, 40 and 100% teff flour than lower or no percentages of teff.

It is important for cookie quality that the gluten is not developed during mixing because this leads to tougher products and reduced cookie spread (Hoseney, 1994). This is favorable to teff since teff does not contain gluten, gluten development during mixing resulting in tougher cookies should be less of a problem (Hoseney, 1994).

Based on an informal sensory evaluation, the texture of the cookies did not appear to be affected by increased teff content. The characteristics of teff flour that impaired cake-quality are more easily concealed in cookies. The fracture strength was measured to determine the ease with which the probe could cut through the cookie. We thought that the same phenomenon that created a cracking pattern on the surface of the teff cookies would also result in a more brittle cookie with increased percentages of teff though there was no significant difference in fracture strengths between treatments (Figure 18).

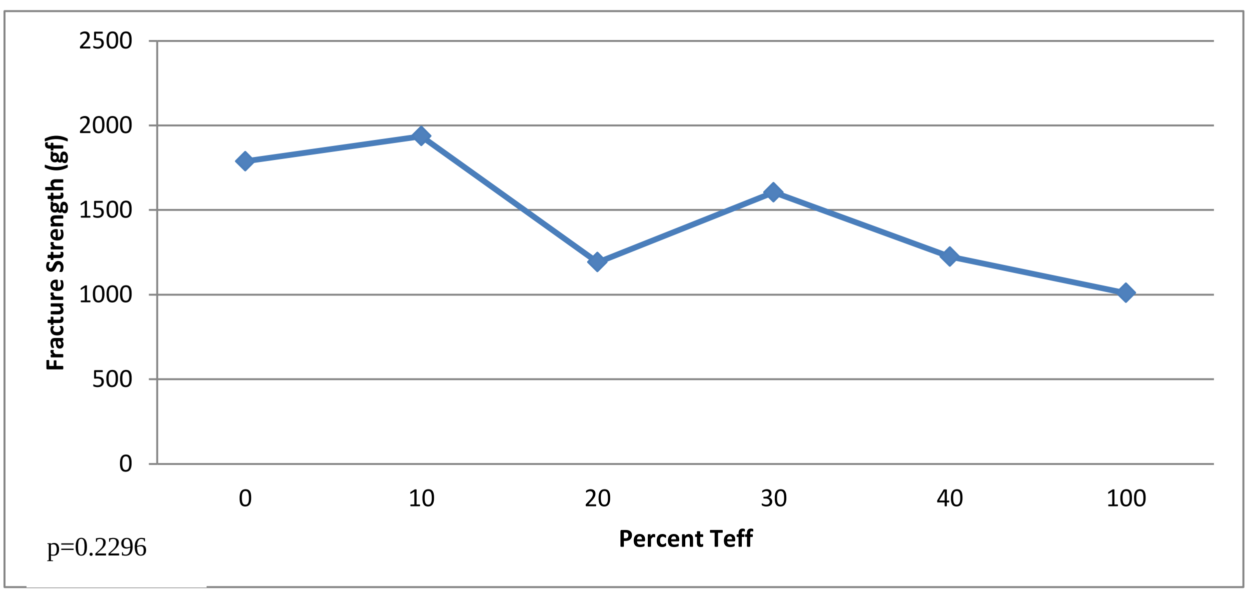


Figure 18. Fracture strength (gf) of cookie samples by percent teff

Cookie Spread

The results indicate that there was only a significant difference in cookie spread between 0% teff and 40% and 100% teff treatments (Figure 20). Cookie spread is a principle determinant of flour quality and is determined by the hydration capacity of the non-starch polysaccharides. The same hemicellulosic fraction in wheat flour that produces a good quality cake is considered quality-impairing for cookies (Pomeranz, 1988). This is because the hemicelluloses are water-insoluble and consequently have a detrimental effect on cookie spread due to their inability to absorb water (Pomeranz, 1988). Conversely, flour constituents or ingredients with a great capacity for absorbing water tend to decrease cookie spread (Pomeranz, 1988). Although the hemicellulosic content of teff flour is unknown, teff flour does not appear to have a great capacity for absorbing water (Figure 19). Despite the inability to retain moisture, increased percentages of teff flour did not significantly impact cookie quality until 40% and 100% teff flour was used (Figure 20).

Figure 19. Increase in cookie spread with increasing percent of teff flour

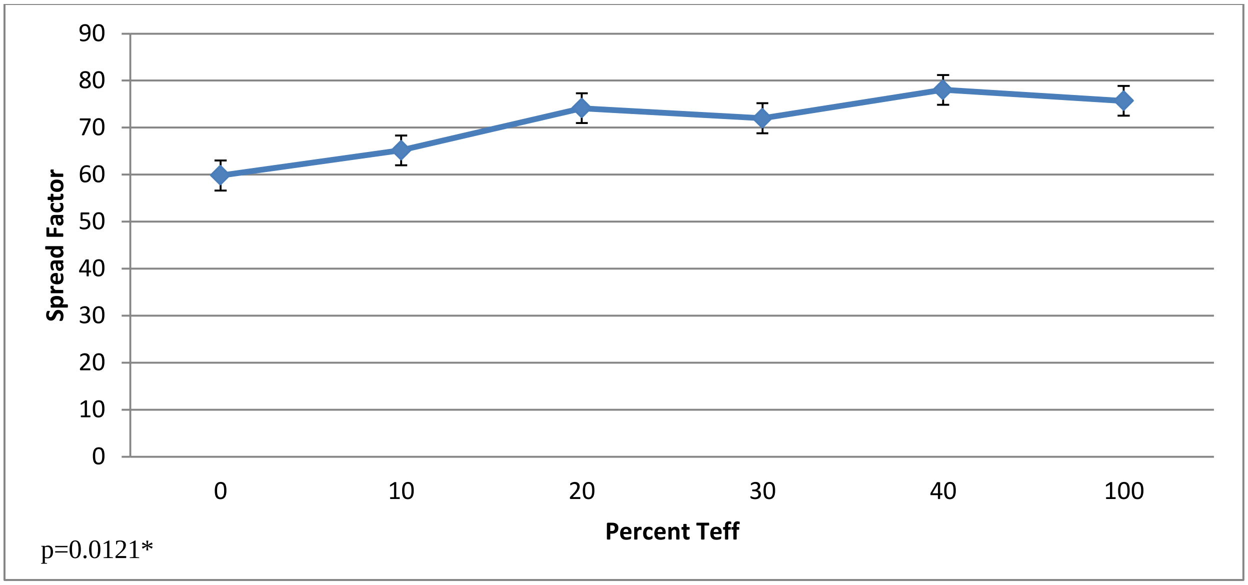


Figure 20. Spread factor (W/T ratio) of cookie samples by percent teff

Color

Color is not a highly-valued physical determinant of cookie quality. Hunter L, a and b-values were measured to contrast cookie color between treatments. Hunter L and b-values decreased with increasing percentages of teff (Figure 21). Specifically, control cookies (with 0% teff) were lighter in color (higher L-values) and more yellow in color (higher (+) b-values) than treatments with higher percentages of teff flour (Figure 22a and 22c). The Hunter L and b-values were therefore significantly different between treatments (Table 13). Hunter a-values demonstrated an upward trend with increasing percentages of teff (Figure 22b). Though the a-values show an increasing trend, there is only a significant difference between 0% teff and all other treatments (Table 13).

Figure 21. Hunter L and b-values decreased with increasing percent of teff

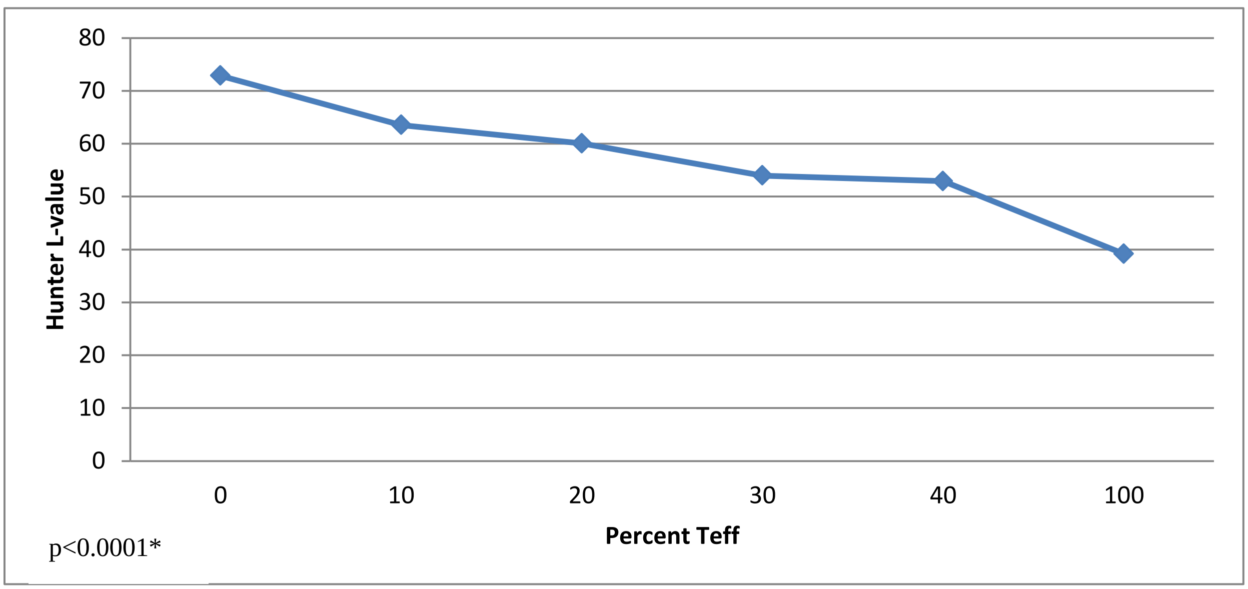


Figure 22a. Changes in Hunter L-values* of cookie samples for different percentages of teff
*L = 0 = black; L = 100 = white

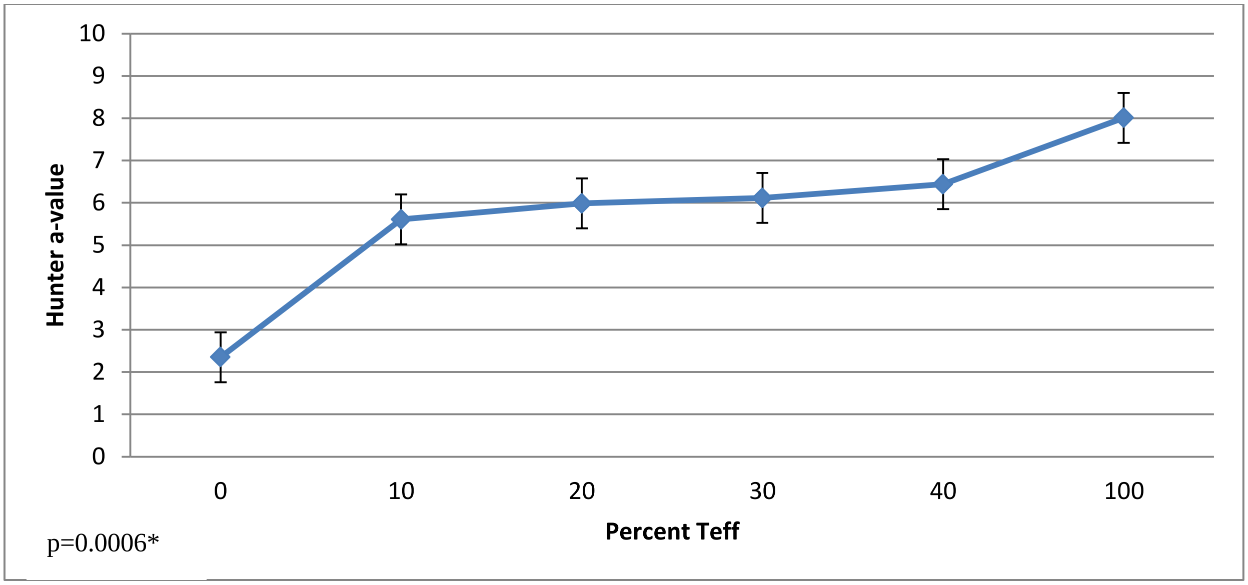


Figure 22b. Changes in Hunter a-values* of cookie samples for different percentages of teff
* +a = red; -a = green

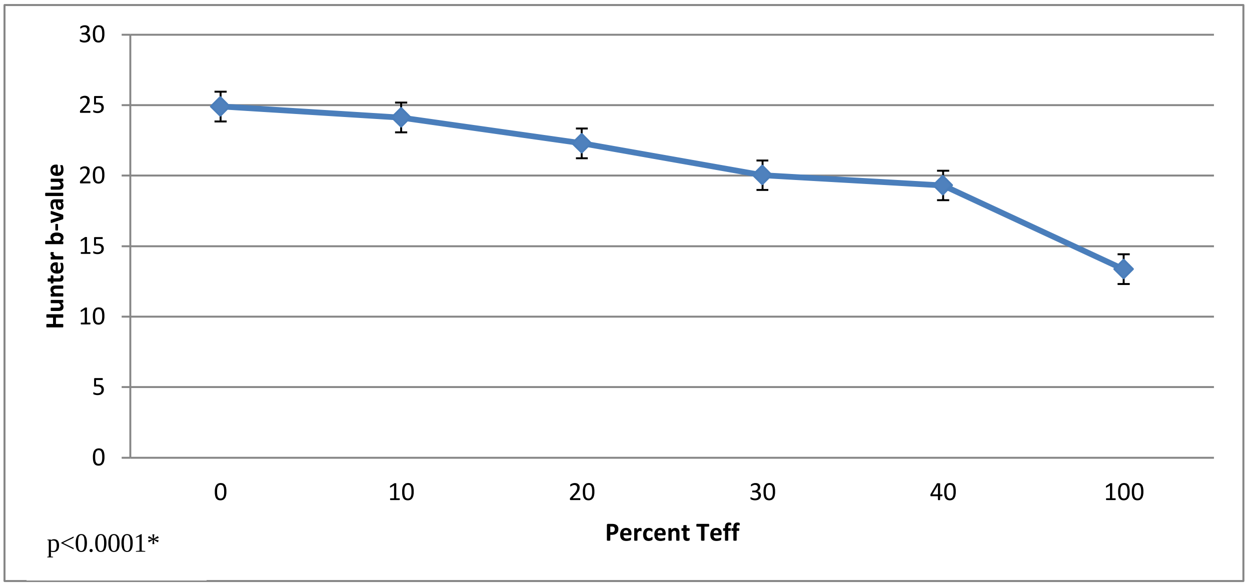


Figure 22c. Changes in Hunter b-values* of cookie samples for different percentages of teff
* +b = blue; -b = green

Table 13. Mean color (Hunter L, a and b-values) of cookie samples for all percentages of teff

Percent Teff	Hunter L-value[1]	Hunter a-value[2]	Hunter b-value[3]
0	4.29[a]	2.35[a]	24.90[a]
10	4.15[b]	5.61[b]	24.12[ab]
20	4.09[b]	5.99[b]	22.29[ab]
30	3.99[c]	6.11[b]	20.03[ab]
40	3.97[c]	6.44[b]	19.30[b]
100	3.67[d]	8.01[b]	13.36[c]

*Levels not connected by the same letter are significantly different at $p \leq 0.05$
[1] L = 0 = black; L = 100 = white
[2] +a = red; -a = green
[3] +b = yellow; -b = blue

4.4.6 Biscuit Product

Texture

Characteristics used to evaluate cookie quality can be applied to biscuit flour quality. It has been reported that flours containing higher fractions of crude hemicelluloses produced less compressible dough and the biscuits prepared from them were smaller in volume (Pomeranz, 1975). The biscuits also were noted to have a less tender crust and crumb than biscuits prepared with greater water-soluble fractions (Pomeranz, 1975). These factors did not appear to affect the quality of texture in biscuit samples with higher teff content and there were no significant differences in compression strengths between any of the treatments of 0 – 40% teff (Figure 23). The biscuits containing 100% teff flour could not be measured due to the hardness of the final product (Figure 24). It is also recommended that biscuit flour should have low protein content and flours with high protein do not produce a satisfactory product. Despite teff's high protein content, this did not appear to impair biscuit quality.

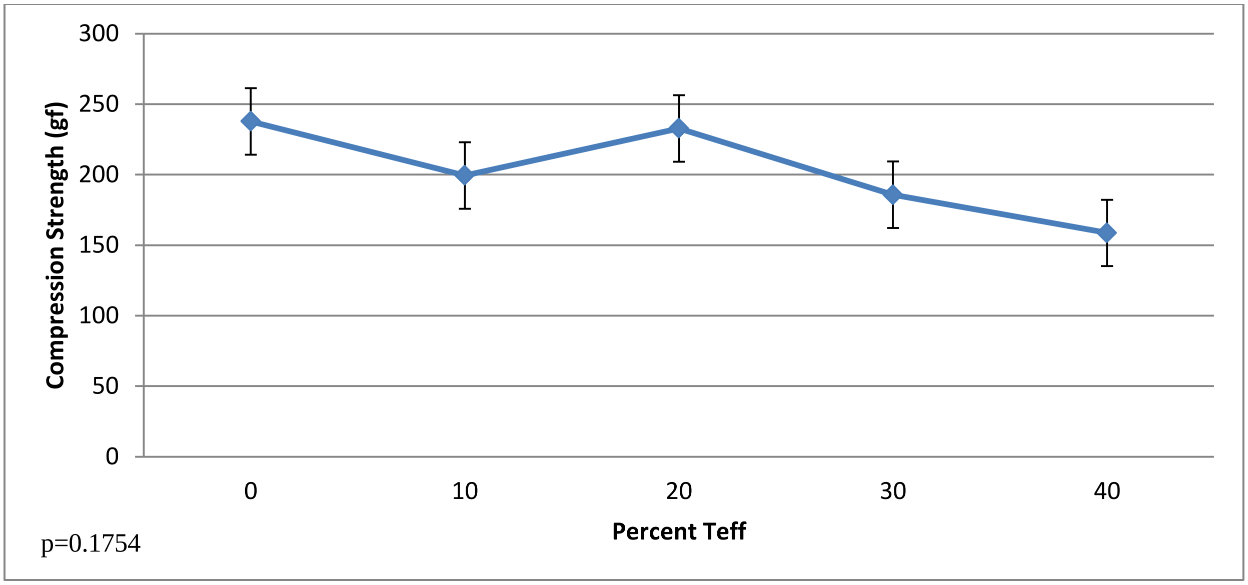


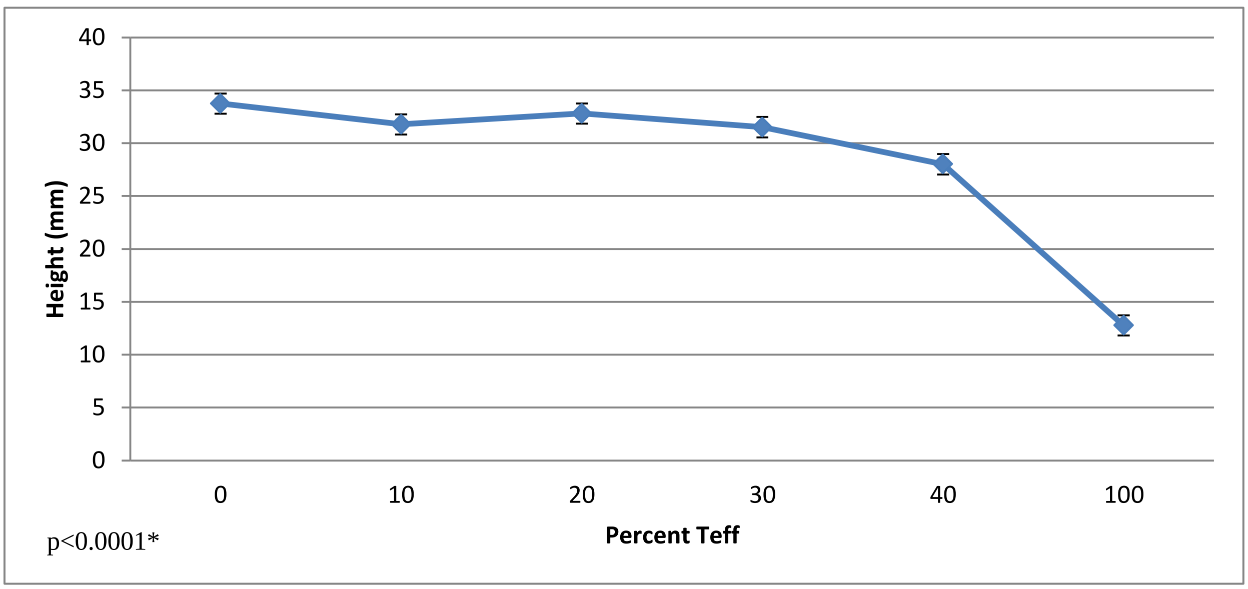
Figure 23. Compression strength (gf) of biscuit samples by percent teff

Figure 24. Biscuit samples containing 100% teff flour

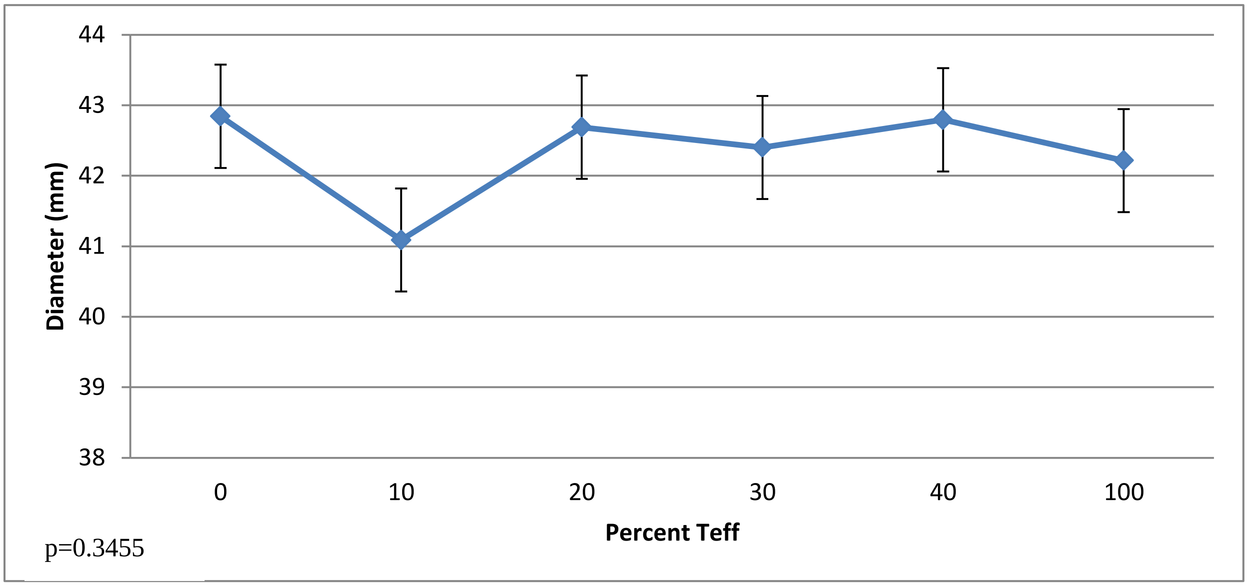
Height, Weight and Diameter

The height, weight and diameter of the biscuit samples were measured to determine biscuit thickness and spread. The results show a downward trend in biscuit height with increasing teff content (Figure 25a). The weight and diameter of the biscuit samples were not significantly different between any of the treatments (Figure 25b and 25c). The mean height, weight and diameter of the biscuit samples are reported in Table 14.

A.



B.



C.

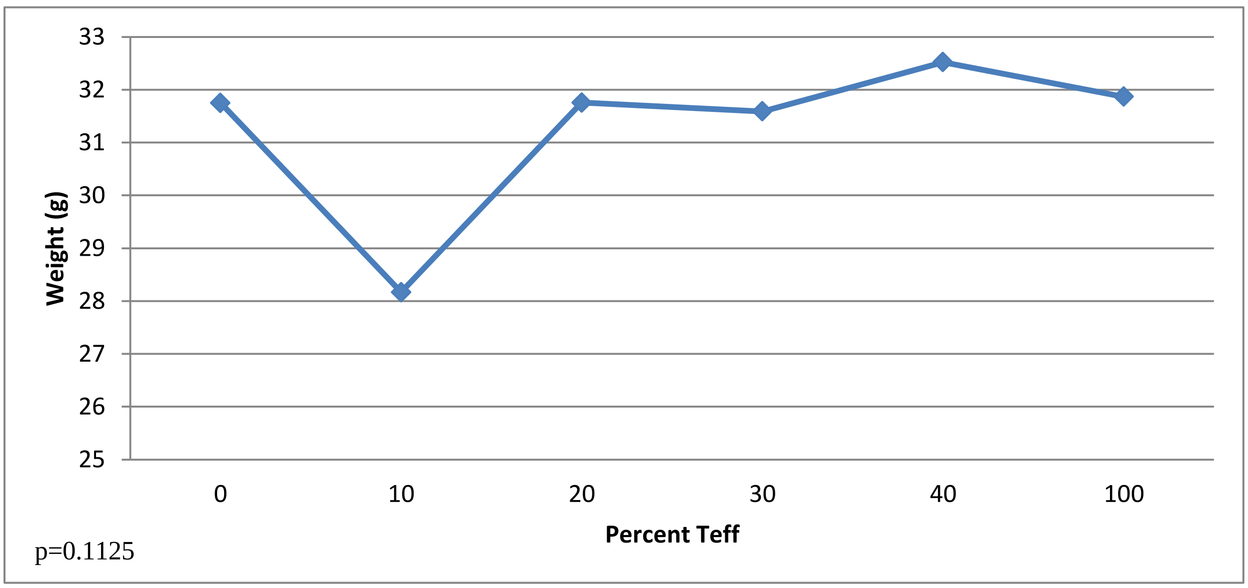


Figure 25. Mean height (A), diameter (B) and weight (C) of biscuit samples by percent teff

Table 14. Mean height (mm), diameter (mm) and weight (g) of biscuit samples for all percentages of teff

Percent Teff	Mean Height (mm)	Mean Diameter (mm)	Mean Weight (g)
0	33.75[a]	48.85[a]	3.17[a]
10	31.78[ab]	46.76[a]	3.05[a]
20	32.80[a]	48.84[a]	3.17[a]
30	31.51[ab]	48.40[a]	3.16[a]
40	28.01[b]	48.93[a]	3.19[a]
100	12.76[c]	48.28[a]	3.17[a]

*Levels not connected by the same letter are significantly different at $p \leq 0.05$

Color

Hunter L, a and b-values were measured for the crumb and crust of the biscuit samples. Figure 26 shows the color spectrum of biscuit samples for 0, 10 and 20% teff flour on the top row and 30, 40 and 100% teff flour on the bottom row. Hunter L-values decrease for the crumb and crust, indicating a darker biscuit with increasing percentages of teff (Figure 27a). Hunter a-values remain relatively stable for the crust and show an increasing trend for the crumb (Figure 27b). Whiteness is not a highly regarded characteristics of biscuit quality, therefore a darker crust and crumb is not undesirable. Hunter b-values decrease with higher teff content (Figure 27c). The mean Hunter L, a and b-values for the crust and crumb of the biscuit samples are reported in Tables 15a and 15b.

Figure 26. Color spectrum of biscuit samples for 0, 10 and 20% teff flour on the top row and 30, 40 and 100% teff flour on the bottom row

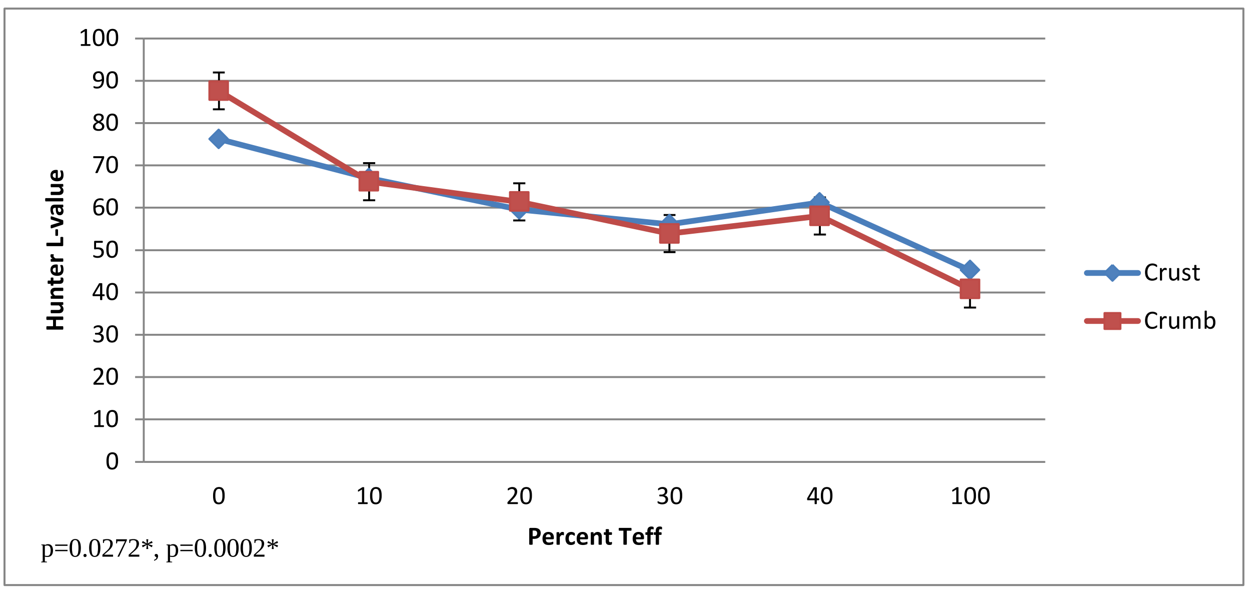


Figure 27a. Changes in Hunter L-values* of biscuit samples for different percentages of teff
*L = 0 = black; L = 100 = white

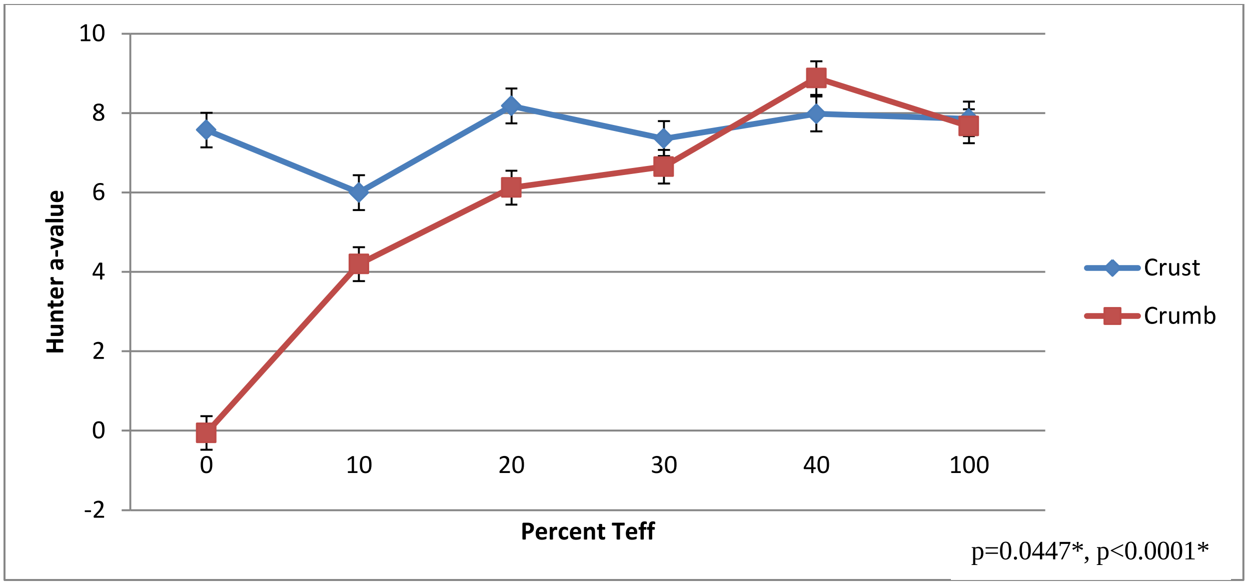


Figure 27b. Changes in Hunter a-values* of biscuit samples for different percentages of teff
* +a = red; -a = green

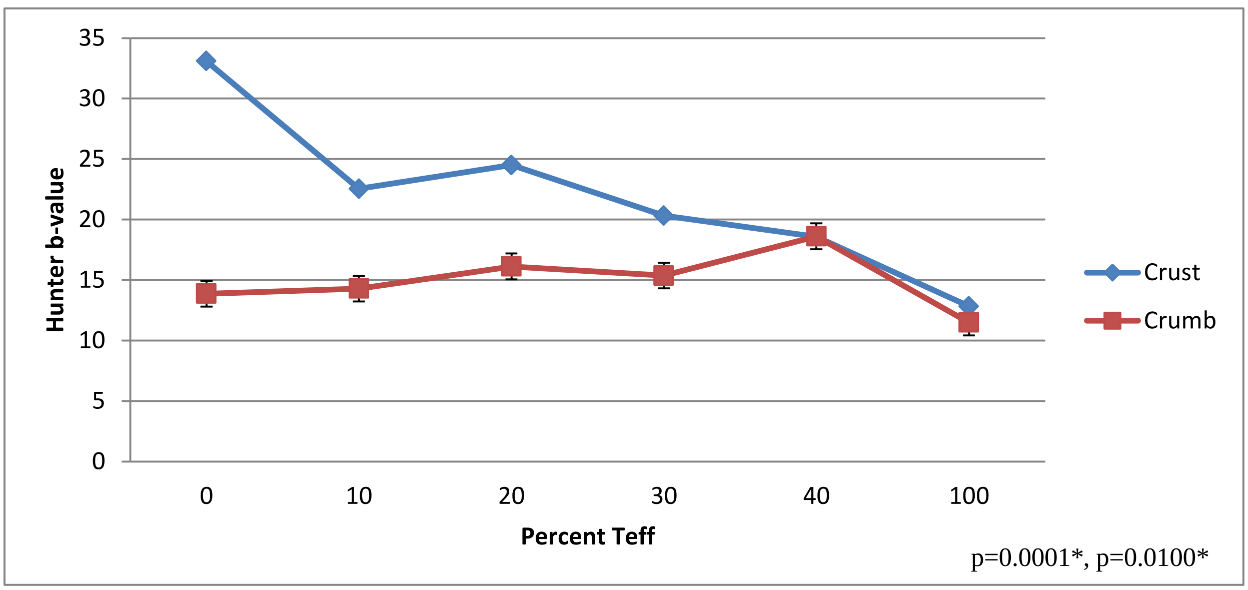


Figure 27c. Changes in Hunter b-values* of biscuit samples for different percentages of teff
* +b = blue; -b = yellow

Table 15a. Mean crust color (Hunter L, a and b-values) of biscuit samples for all percentages of teff

Percent Teff	Hunter L-value[1]	Hunter a-value[2]	Hunter b-value[3]
0	4.32[a]	7.57[ab]	3.49[a]
10	4.19[a]	6.00[b]	3.11[b]
20	4.09[ab]	8.18[a]	3.20[ab]
30	4.03[ab]	7.36[ab]	3.01[b]
40	4.10[ab]	7.98[ab]	2.92[b]
100	3.81[b]	7.85[ab]	2.55[c]

*Levels not connected by the same letter are significantly different at $p \leq 0.05$
[1] L = 0 = black; L = 100 = white
[2] +a = red; -a = green
[3] +b = yellow; -b = blue

Table 15b. Mean crumb color (Hunter L, a and b-values) of biscuit samples for all percentages of teff

Percent Teff	Hunter L-value[1]	Hunter a-value[2]	Hunter b-value[3]
0	87.59[a]	-0.06[d]	13.86[ab]
10	66.16[b]	4.20[c]	14.29[ab]
20	61.40[bc]	6.12[bc]	16.12[ab]
30	53.88[bc]	6.65[b]	15.36[ab]
40	58.04[bc]	8.88[a]	18.61[a]
100	40.79[c]	7.67[ab]	11.48[b]

*Levels not connected by the same letter are significantly different at $p \leq 0.05$
[1] L = 0 = black; L = 100 = white
[2] +a = red; -a = green
[3] +b = yellow; -b = blue

4.4.7 Bread Product

Texture

The sponge-dough method is recommended for breads baked with heavier flours, such as teff, in order to better incorporate the flour into the dough mixture and improve texture and volume of the final product. The properties of good bread are opposite to those of a good biscuit. For yeast-leavened breads, a protein content of at least 11% is preferable. Though teff contains high protein content, the texture still appeared to be significantly affected with increased percentages of teff. Though teff meets the protein content requirements, impaired quality may be attributed to teff's lack in protein quality. The compression strength of the loaf and slice of each bread sample was measured (Figure 28). The data showed that there is a significant difference between 0 and 10% teff compared to 40% teff. Measurements could not be obtained on loaves containing 100% teff flour due to the hardness of the product samples.

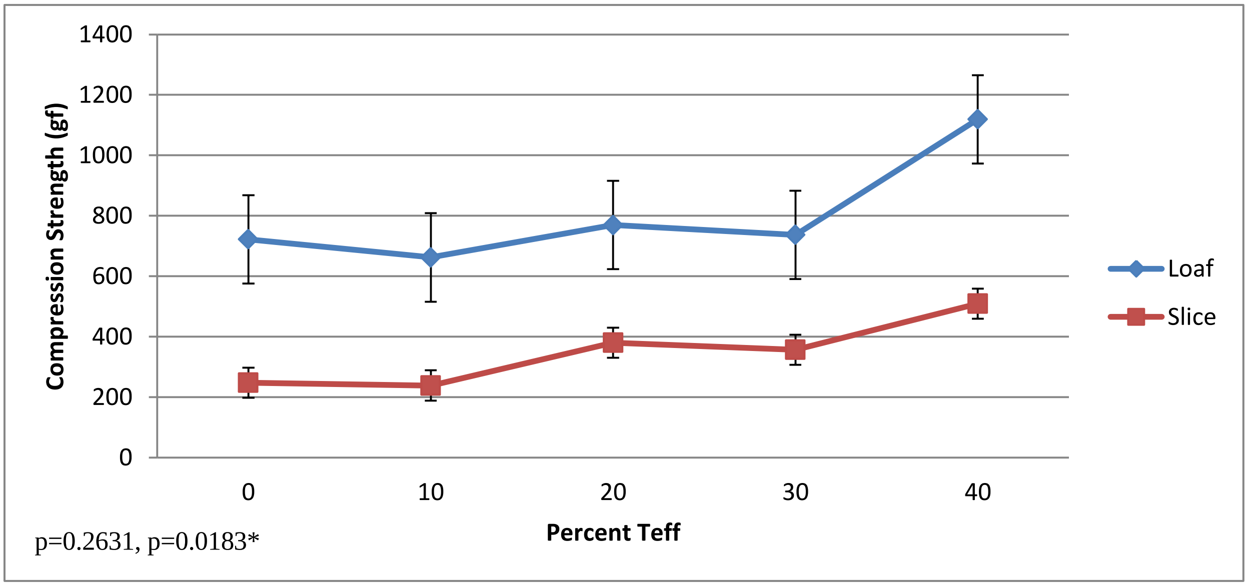


Figure 28. Compression strength of bread samples measured for loaf and slice by percent teff

Volume

Despite a declining trend in volume with increased percentages of teff, the results indicated that there is only a significant difference between 100% teff and all other treatments (Figure 30). The mean values for volume between treatments are reported in Table 16. The structure of the dough involves a gluten protein matrix which consists of strings of small starch granules glued together by gluten proteins (Pomeranz, 1988). Well-developed gluten and high quality proteins enable the gluten structure to better retain carbon dioxide released by the yeast in the dough and loaf volume is a good indicator of gas retention in the dough (Pomeranz, 1988). The lack of gluten in teff flour prevented this process from taking place (Figure 29). Low protein levels, poor dough development and lack of oxidation are all factors that adversely affected the gas-holding properties of bread samples baked with teff flour.

Figure 29. Comparison of loaf volume at 0% and 100% teff flour

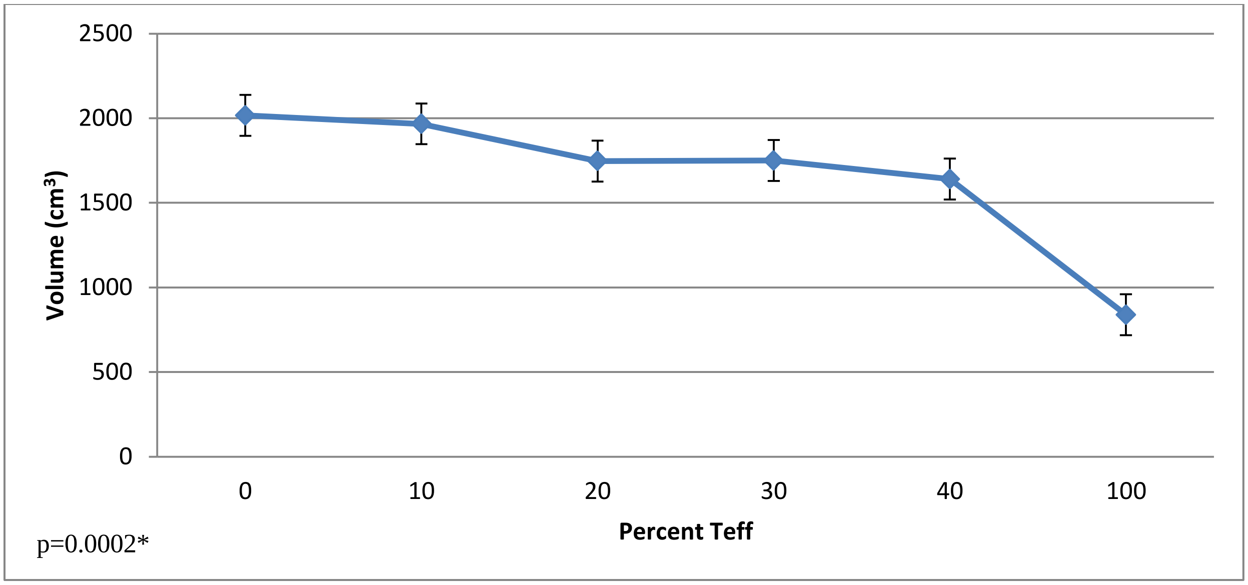


Figure 30. Mean changes in volume of bread loaves by percent teff

Table 16. Mean volume of bread loaves by percent teff

Percent Teff	Mean Volume (cm3)
0	2016.67[a]
10	1966.67[a]
20	1746.67[a]
30	1750.00[a]
40	1640.00[a]
100	838.33[b]

*Levels followed by the same letter are not significantly different at $p \leq 0.05$

Color

Traditionally, a white bread crumb with excellent light reflection was preferred (Pomeranz, 1988). However, in recent years, consumer preferences are shifting more and more to a whole-wheat alternative. The wheat pigments and bran content affects the whiteness of baked products (Pomeranz, 1988). Light reflection is improved by fine and even porous structure which is why the crumb appears whiter than the crust (Pomeranz, 1988). Ash content, on the other hand, correlates with a more gray cast and dull appearance (Pomeranz, 1988). Grade color of the flour also influences crumb color of bread and is dependent on the extraction rate and amount of bleaching given to the flour (Hui, 2006). Similarly, darker flours produce grayer, duller bread crumbs.

Teff has a higher ash content compared to wheat flour and darker, untreated flour. It was therefore expected that color measurements on the crumb and crust of teff bread samples will reveal a darker, duller appearance than control samples baked with 100% wheat flour. Contradictory to this assumption, the Hunter L-values showed an upward trend for the crust color and only a moderate decline in Hunter L-values for the crumb (Figure 31a). This indicated that the browning of the crust is not necessarily any darker when teff what incorporated into the bread samples than samples containing higher amounts of wheat. Hunter a-values also show a conflicting trend between the color of the crumb and crust with crust values decreasing while the a-values of the crumb increase (Figure 31b). The Hunter b-values decline with increasing teff flour for the crumb and crust which correlates with a duller, grayer color (Figure 31c). The mean Hunter L, a and b-values for the crust and crumb of the bread samples are reported in Tables 17a and 17b.

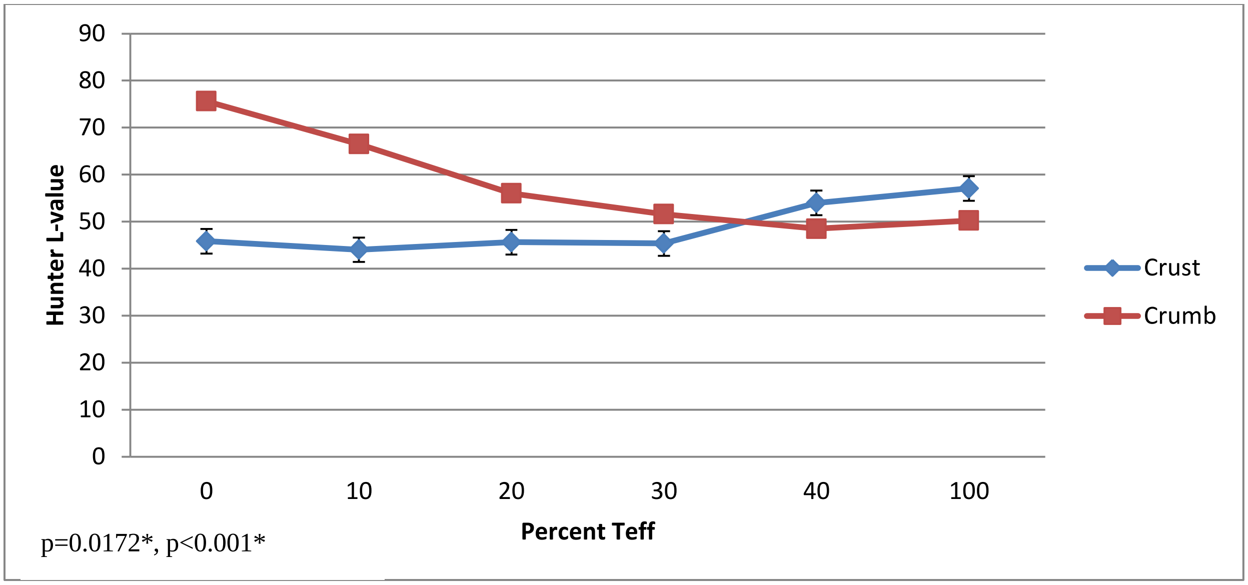


Figure 31a. Changes in Hunter L-values* of bread samples for different percentages of teff
*L = 0 = black; L = 100 = white

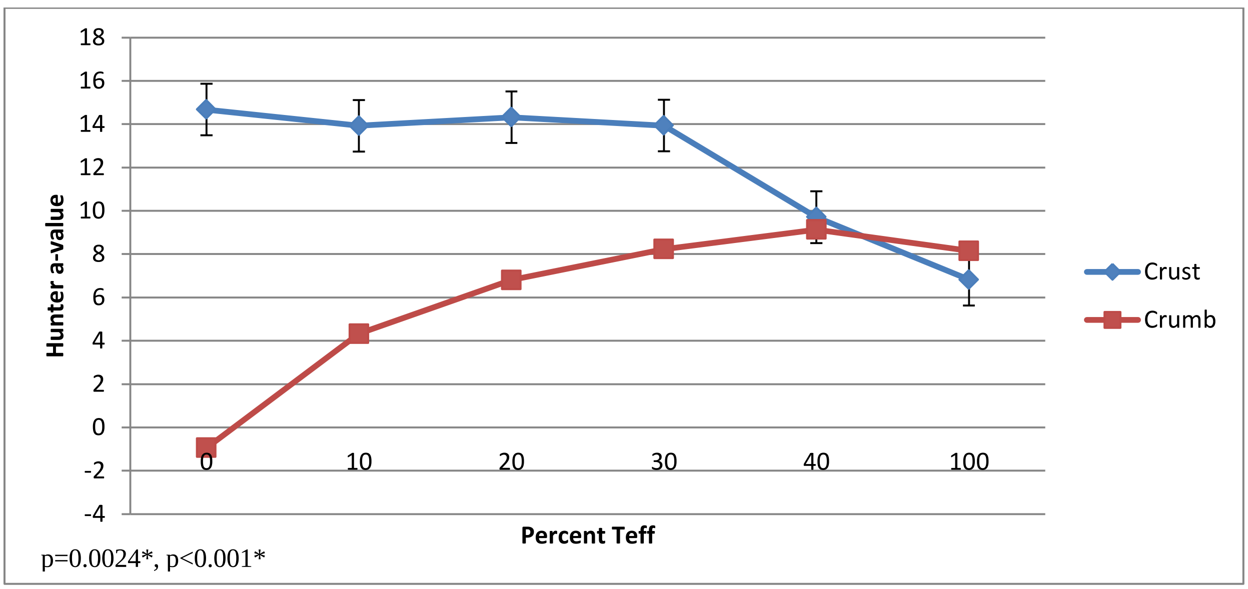


Figure 31b. Changes in Hunter a-values* of bread samples for different percentages of teff
* +a = red; -a = green

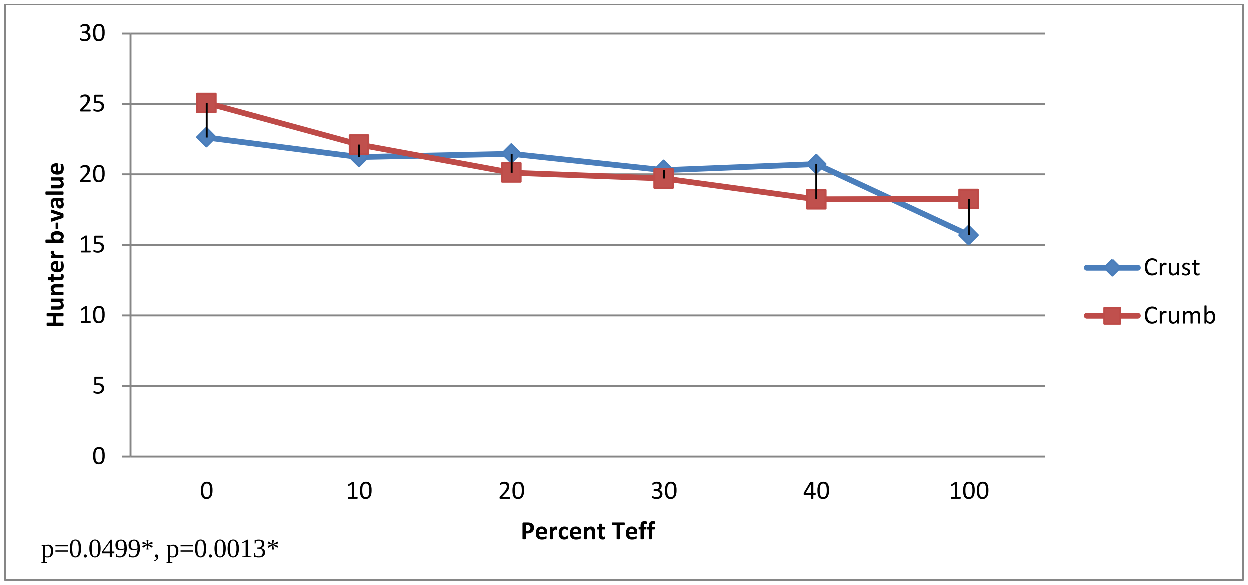


Figure 31c. Changes in Hunter L-values* of bread samples for different percentages of teff
* +b = blue; -b = yellow

Table 17a. Mean crust color (Hunter L, a and b-values) of bread samples for all percentages of teff

Percent Teff	Hunter L-value[1]	Hunter a-value[2]	Hunter b-value[3]
0	45.84[ab]	14.67[a]	22.62[a]
10	44.02[b]	13.92[a]	21.23[ab]
20	45.62[ab]	14.32[a]	21.46[ab]
30	45.36[ab]	13.94[a]	20.31[ab]
40	53.97[ab]	9.71[ab]	20.72[ab]
100	57.05[a]	6.82[b]	15.69[b]

*Levels not connected by the same letter are significantly different at $p \leq 0.05$
[1] L = 0 = black; L = 100 = white
[2] +a = red; -a = green
[3] +b = yellow; -b = blue

Table 17b. Mean crumb color (Hunter L, a and b-values) of bread samples for all percentages of teff

Percent Teff	Hunter L-value[1]	Hunter a-value[2]	Hunter b-value[3]
0	75.64[a]	-0.94[d]	25.07[a]
10	66.49[b]	4.32[c]	22.11[ab]
20	56.01[c]	6.81[b]	20.12[b]
30	51.58[c]	8.23[ab]	19.71[b]
40	48.50[c]	9.14[a]	18.23[b]
100	50.23[c]	8.15[ab]	18.25[b]

*Levels not connected by the same letter are significantly different at $p \leq 0.05$

[1] L = 0 = black; L = 100 = white

[2] +a = red; -a = green

[3] +b = yellow; -b = blue

4.4.8 Other Products

In addition to the more traditional baked products, we also experimented with the use of teff flour in other trial products. While some attempts were a complete failure, such as the use of teff in tortillas and pita bread, others were a great success. Products that did well with teff flour were crepes, dumplings, zucchini bread and apple nut bread.

The most promising products, however, were teff crackers and teff pizza crust. The crackers were baked with a combination of herbs and cheese which we called “Rosemary and Parmesan Teff Crackers” (Figure 32) (see Appendix F for recipe). Teff flour in combination with other gluten-free flours, such as rice, tapioca or guar gum flour, also produced a very successful and delectable gluten-free pizza dough (see Appendix G for recipe).

Figure 32. Rosemary parmesan teff crackers

4.5 Summary and Conclusion

While it was possible to bake cakes and bread with lower percentages (10, 20 and 30%) of teff, the quality of the final product was severely impaired at higher concentrations (40 and 100%) of teff flour. We feel that biscuits and cookies were teff's more promising products. Cookies, in particular, did very well with increasing percentages of teff and cookies containing 30 – 40% teff were actually preferred over the control cookies. The flavor of teff seems to be complemented with the addition of sugar. Since cookie flour does not require gluten proteins, as is the case with cakes, cookies were an excellent fit for incorporating teff. None of the baked goods produced an acceptable product using 100% teff flour. Additionally, the use of teff in crackers and pizza crust produced a very satisfactory final product. The flavor of teff was also complemented by Italian seasonings which is why the crackers and pizza were so successful. Overall, the success of teff in baked products is limited by need for gluten-development.

4.6 References

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Chapter 5

Summary, Conclusions and Recommendations

5.1 Summary and Conclusions

Growing trends in the number of health food stores and aisles in the grocery store designated organic represents a new direction in consumer behavior. Interest in a more health-conscientious diet has led to a demand for foods that are tasty, nutritious and environmentally friendly. This is never so evident as in the total sales of natural and organic foods which were estimated to reach $28.2 billion in 2006 alone (Food Marketing Institute, 2007). This consumer trend is driven by the search for diets that promote health and well-being, prevent diseases, help cure illnesses and protect the environment (Food Marketing Institute, 2007).

With such growing demands, there seems to be more and more of a place for alternative food crops in traditional crop production. In fact, as much as 2.8 million acres of cropland and pastureland is now dedicated to production of organic and natural foods (FMI, 2007). The objectives of this study were developed around the potential ability of teff to fulfill this niche. Teff's unique nutritional qualities are frequently cited as beneficial to patients diagnosed with anemia, osteoporosis and Celiac Disease. Teff is both exceptionally high in iron, calcium and protein while providing a gluten-free alternative to those who cannot tolerate gluten. Since teff is a native crop to the highlands of Ethiopia, simply recommending teff as an alternative grain crop is futile without properly assessing its agronomic characteristics and grain yield potential in Virginia. Secondly, if teff can be successfully establish and grown in Virginia, then it is dually important to determine teff's uses once produced.

Our two-year field study revealed mixed results. In 2010, teff performed significantly better compared to 2011. In both experimental years, temperature and precipitation were both within teff's requirements for optimum production. The brown variety far exceeded the yield of the white variety with varieties averaging 366 kg ha^{-1} and 96 kg ha^{-1}, respectively. Interestingly, there was no significant difference in grain yield among planting dates which suggests flexibility in planting dates without significant reduction in grain yield. Of course, planting date is still dependent on environmental conditions such as rainfall for successful establishment. Though grain yield in Virginia averaged at best only 366 kg ha^{-1} compared to the 910 kg ha^{-1} produced annually in Ethiopia, we feel that this is the result of varieties that may or may not have been grain types, and agronomic practices rather than the ability of the grain to be successfully produced in the area.

Alternatively, teff is also used for forage in the United States and straw yield averaged 2500 kg ha^{-1} on our plots grown in Virginia. Crude protein, ADF and NDF were also used to determine straw quality. The white variety was significantly higher in crude protein compared to the brown variety with values averaging 11.7% and 9.0%, respectively. The 9.0% CP values reported for the brown teff straw can satisfy the nutritional requirements of all livestock at the maintenance level while the 11.7% CP for the white teff straw can satisfy the nutritional requirements of animals above maintenance level (such as growing and milking animals). The ADF values for the brown and white teff straw were not significantly different while NDF for the brown straw was significantly higher than the white teff straw. The ADF and NDF values for brown vs. white teff straw ranged from 42.4 and 40.9%, and 71.5 and 67.9%, respectively. These values are within the acceptable level to satisfy the nutritional requirements of cattle at different production levels.

Transitioning from field to fork, the baking characteristics were also evaluated to determine whether products baked with teff flour could gain consumer acceptance. To evaluate the backing characteristics of teff, cakes, cookies, bread and biscuits were made with varying percentages of teff and wheat flour. For the cakes and bread, there was an apparent decline in product volume with an increase in the percent of teff. The reduced volume was to the extent that it hindered desirability of the final product and is therefore not recommended. On the other hand, cookies and biscuits baked best at a percent of 10-30% teff and biscuits and cookies containing teff were actually preferred more than the controls. In addition to the tested products, other baked goods that complimented teff flour were crackers, crepes, zucchini bread, banana-berry bread and pizza dough. Incorporating teff flour into all baked products achieved maximum performance at less than 50% teff flour.

5.2 Recommendations

Due to lack of scientific literature and agronomic practices in growing teff for grain in the United States, most of our information was acquired through personal communications which resulted in many trial and errors. In our case, the failure to establish teff as the result of poor agronomic practices provided constructive guidance for future research. The following cultural practices and management conditions are recommended for future research in teff grain production: (1) effective weed control methods; (2) successful establishment (control of seeding depth and seed-to-soil contact); (3) higher yielding varieties (grain type) suitable to Virginia's growing conditions; and (4) more effective and reliable harvesting and threshing methods. At this point in time, it would be difficult to recommend teff for large-scale grain production in Virginia. High initial investment and variability in our results presents too much of a risk.

Though time constraint was a factor in the baked experiments, we can make many recommendations for future product testing. For simplicity, products were tested using only teff and wheat flour. Had time and resources permitted, we would like to have conducted tests on composites of teff with other gluten-free flours. Additionally, we would have liked to expand the products which were being tested. Our research was refined to only baked goods but it would be interesting to see how teff may perform in products that do not rely so heavily on gluten development, as is the case with cakes and bread. For example, teff has been cited for use in cooking.

Additionally, there was no measurable decline in product quality of the cookies and biscuits until we used 100% teff flour. It would have been useful to know at what point between 40% and 100% teff flour the decline in product quality might have occurred. A formal sensory evaluation would have also been useful to determine consumer acceptance of baked products. Even when the results showed a decline in volume or spread, often the taste of the product was quite desirable at 10-40% teff flour. For any product other than injera, the use of 100% teff flour is not recommended. Ingredients that serve as a binding agent are also helpful in reducing crumbliness of products containing higher percentages of teff flour, such as honey, peanut butter or syrup.

Glossary

Aerodynamic drag	"The opposing force encountered by a body moving relative to a fluid; e.g., an aircraft in flight displacing the air in its path." (Terminology, 2005)
Albumin	"A group of relatively small proteins that are soluble in water and readily coagulated by heat. Ovalbumin is the main protein of egg-white, lactalbumin occurs in milk, and plasma or serum albumin is one of the major blood proteins. Serum albumin concentration is sometimes measured as an index of protein-energy malnutrition. Often used as a non-specific term for proteins (e.g. albuminuria is the excretion of proteins in the urine)." (2009)
Aleurone	"Protein found in the outer skin of seeds." (1998)
Amino acids	"The basic units from which proteins are made. Eleven of the amino acids involved in proteins can be synthesized in the body, and so are called non-essential or dispensable amino acids, since they do not have to be provided in the diet. They are alanine, arginine, aspartic acid, asparagine, cysteine, glutamic acid, glutamine, glycine, proline, serine, and tyrosine. Nine amino acids cannot be synthesized in the body at all and so must be provided in the diet; they are called the essential or indispensable amino acids—histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. The limiting amino acid of a protein is that essential amino acid present in least amount relative to the requirement for that amino acid. The ratio between the amount of the limiting amino acid in a protein and the requirement for that amino acid provides a chemical estimation of the nutritional value (protein quality) of that protein, termed chemical score. Most cereal proteins are limited by lysine, and most animal and other vegetable proteins by the sum of methionine + cysteine (the sulfur amino acids)." (Bender, 2005)
Anemia	"The condition of having a lower-thannormal number of red blood cells or quantity of hemoglobin. Anemia diminishes the capacity of the blood to carry oxygen. Patients with anemia may feel tired, fatigue easily, appear pale, develop palpitations, and become short of breath. Children with chronic anemia are prone to infections and learning problems. The main causes of anemia are bleeding, hemolysis (excessive destruction of red blood cells), underproduction of red blood cells (as in bone marrow diseases), and underproduction of normal hemoglobin (as in sickle cell anemia and in iron deficiency anemia). Women are more likely

than men to have anemia because of menstrual blood loss. In children, anemia is most commonly due to insufficient iron in the diet. Anemia is also often due to gastrointestinal bleeding caused by medications, including such common drugs as aspirin and ibuprofen.” (WebMd, 2009)

Antioxidant “Highly reactive oxygen radicals are formed during normal oxidative metabolism and in response to infection and some chemicals. They cause damage to fatty acids in cell membranes, and the products of this damage can then cause damage to proteins and DNA. The most widely accepted theory of the biochemical basis of much cancer, and also of atherosclerosis, is that the key factor in precipitating the condition is tissue damage by radicals.” (Bender, 2005)

Arabinose “The main non-cellulosic, non-starch cell wall polysaccharide in the tissues of cereal plants and wheat flour.” (Pomeranz 1997).

Ascorbic acid “Vitamin C, an essential nutrient found mainly in fruits and vegetables. The body requires ascorbic acid in order to form and maintain bones, blood vessels, and skin. Ascorbic acid also promotes the healing of cuts, abrasions and wounds; helps fight infections; inhibits conversion of irritants in smog, tobacco smoke, and certain foods into cancer-causing substances; appears to lessen the risk of developing high blood pressure and heart disease; helps regulate cholesterol levels; prevents the development of scurvy; appears to lower the risk of developing cataracts; and aids in iron absorption.” (WebMd, 2009)

Baking powder “A mixture that liberates carbon dioxide when moistened and heated. The source of carbon dioxide is sodium bicarbonate, and an acid is required. This may be cream of tartar or calcium acid phosphate, etc.” (Bender, 2005)

Baking soda “Or bicarbonate of soda, chemically sodium bicarbonate, the source of carbon dioxide in baking powder.” (Bender, 2005)

Bran “The outside covering of the wheat seed, removed when making white flour, but an important source of roughage and some vitamin B.” (1998)

Carbohydrate “Carbohydrates are the major source of metabolic energy, the sugars and starches. Chemically they are composed of carbon, hydrogen, and oxygen in the ration of C_n:H_{2n}:O_n. The basic carbohydrates are the monosaccharide sugars, of which glucose, fructose, and galactose are the most important nutritionally.

	Disaccharides are composed of two monosaccharides: nutritionally the important disaccharides are sucrose (a dimer of glucose + fructose), lactose (a dimer of glucose + galactose) and maltose (a dimer of two glucose units). A number of oligosaccharides occur in foods, consisting of 3-5 monosaccharide units; in general these are not digested, and should be considered among the unavailable carbohydrates. Larger polymers of carbohydrates are known as polysaccharides or complex carbohydrates. Nutritionally, two classes of polysaccharides can be distinguished: (1) starches, which are polymers of glucose units, either as a straight chain (amylose) or with a branched structure (amylopectin) and are digested; and (2) a variety of other polysaccharides which are collectively known as non-starch polysaccharides (NSP), and are not digested by human digestive enzymes. Carbohydrates form the major part of the diet, providing between 50 and 70% of the energy intake, largely from starch and sucrose." (Bender, 2005)
Celiac disease (CD)	"An immune disorder whereby the small intestine is injured when exposed to gluten, a protein found in wheat and related grains. Celiac disease causes impaired absorption and digestion of nutrients through the small intestine. Symptoms include frequent diarrhea and weight loss. The most accurate test for celiac disease is a biopsy of the small bowel. Treatment involves avoidance of gluten in the diet. Also known as gluten enteropathy." (WebMd, 2009)
Chlorine	"Chlorine gas is used for bleaching and improving flour, its effect being to remove the color from the fat. Chlorine also rapidly matures flour so that it acts as if naturally aged and denatures gluten thus assisting in the preparation of high ratio cake flours." (Daniel, 1971)
Denaturation, protein	"A change in the structure of protein by heat, acid, alkali, or other agents which results in loss of solubility and coagulation. It is normally irreversible. Denatured proteins lose their biological activity (e.g. as enzymes), but not their nutritional value." (Bender, 2005)
Disaccharide	"Sugars composed of two monosaccharide units; the nutritionally important disaccharides are sucrose, lactose, and maltose. *See* CARBOHYDRATE." (Bender, 2005)
Egg	"Useful in food preparation to thicken sauces and custard, as an emulsifier, to hold air in meringues and sponges, and as a binder in croquettes." (Bender, 2005)

Egg proteins "What is generally referred to as egg protein is a mixture of individual proteins, including ovalbumin, ovomucoid, ovoglobulin, conalbumin, vitellin, and vitellenin. Egg-white contains 10.9% protein, mostly ovalbumin; yolk contains 16% protein, mainly two phosphoproteins, vitellin and vitellenin." (Bender, 2005)

Elasticity "Spontaneously resuming its normal bulk or shape after contraction, dilation, compression or distortion. Springy, flexible, hence elasticity. Gluten is said to possess elasticity but as it does not resume its original shape when stretched this is not the best term to use. Extensibility is more appropriate." (Daniel, 1971)

Endosperm "Albumin enclosed with the embryo in seeds; the interior of wheat germ is formed from floury endosperm which is a valuable food source." (1998)

Fat "Chemically fats (or lipids) are substances that are insoluble in water but soluble in organic solvents such as ether, chloroform, and benzene, and are actual or potential esters of fatty acids. The term includes triacylglycerols, phospholipids, waxes, and sterols. In more general use the term 'fats' refers to the neutral fats which are triacylglycerols, mixed with esters of fatty acids with glycerol." (Bender, 2005)

Fermentation "Used loosely to describe any process similar to the action of yeast or leaven in a dough with the evolution of gas, heat and change of properties. The term can be used in connection with all chemical changes brought about by bacteria as well as by yeast. Panary fermentation is the fermentation of bread and bun doughs. Alcoholic fermentation is that in which yeast produces carbon dioxide and alcohol. It occurs in the making of bread, beer, wines, and spirits." (Daniel, 1971)

Floret "Littler flower which forms parts of a larger composite flower head." (1998)

Gelatinization "Formation of water-retentive gel by expansion of starch granules when heated in moist conditions." (Bender, 2005)

Germ "Part of an organism which develops into a new organism and a central part of the seed, formed of the embryo, contains valuable nutrients." (1998)

Gliadin "One of the proteins that make up wheat gluten. Allergy to, or intolerance of, gliadin is celiac disease." (Bender, 2005)

Globulins "Globular (as opposed to fibrous) proteins that are relatively insoluble in water, but soluble in dilute salt solutions. They occur in blood (serum globulins, including immunoglobulins), milk (lactoglobulins), and some plants." (Bender, 2005)

Glutamic acid "A non-essential amino acid; it is acidic since it has two carboxylic acid groups; its amide is glutamine." (Bender, 2005)

Gluten "The protein complex in wheat, and to a lesser extent rye, which gives dough the viscid property that holds gas when it rises. There is none in oats, barley, or maize. It is a mixture of two proteins, gliadin and glutelin. Allergy to, or intolerance of, the gliadin fraction of gluten is celiac disease. In the undamaged state with extensible properties it is termed vital gluten; when overheated, these properties are lost and the product, devitalized gluten, is used for protein enrichment of foods." (Bender, 2005)

Glutenin "A protein forming a constituent of gluten and which imparts the strong characteristic to that substance. Glutenin is insoluble in water or salt solution but soluble to some extent in dilute alkalis or acid." (Daniel, 1971)

Hemicelluloses "Complex carbohydrates included as dietary fiber, composed of polyuronic acids combined with xylose, glucose, mannose, and arabinose. Found together with cellulose and lignin in plant cell walls." (Bender 2005).

Hemoglobin "The oxygen-carrying protein pigment in the blood, specifically in the red blood cells. Abbreviated Hb. Hb is usually measured as total Hb expressed as the amount of Hb in grams (gm) per deciliter (dl) of whole blood. The normal ranges are approximately 14 to 17 gm/dl for adult men and 12 to 15 gm/dl for adult women. Values returned on Hb tests may vary slightly between laboratories." (WebMd, 2009)

Injera "The national bread of Ethiopia, made from a fermented batter of water and a flour from a form of millet (teff)." (Anderson and Anderson, 1993)

L*a*b* values "Represent a color space created for measuring the color of an object where L* measures the lightness of a color and a* and b* are equal to chromaticity, indicating the direction of the color coordinate." (Cachaper, 2005b)

Lamina	"The blade of a leaf." (1998)
Lipids	"A general term for fats and oils, waxes, phospholipids, steroids, and terpenes. Their common property is insolubility in water and solubility in hydrocarbons, chloroform, and alcohols." (Bender, 2005)
Lodging	"The tendency of cereal crops to bend over, so that they lie more or less flat on the ground. Lodging can be caused by wet weather or high winds, and also by disease such as eyespot it can cause problems for harvesting the crop."
Lysine	"An essential amino acid of special nutritional importance, since it is the limiting amino acid in many cereals. Can be synthesized on a commercial scale, and when added to bread, rice, or cereal-based animal feeds, it improves the nutritional value of the protein." (Bender 2005)
Methionine	"An essential amino acid; one of the three containing sulfur; cystine and cysteine are the other two. Cystine and cysteine are not essential, but can only be made from methionine, and therefore the requirement for methionine is lower if there is an adequate intake of cysteine." (Bender 2005)
Osteoporosis	"Thinning of the bones, with reduction in bone mass, due to depletion of calcium and bone protein. Osteoporosis predisposes a person to fractures, which are often slow to heal and heal poorly. It is most common in older adults, particularly postmenopausal women, and in patients who take steroids or steroidal drugs. Unchecked osteoporosis can lead to changes in posture, physical abnormality (particularly the form of hunched back known colloquially as dowager's hump), and decreased mobility. Treatment of osteoporosis includes exercise (especially weight-bearing exercise that builds bone density), ensuring that the diet contains adequate calcium and other minerals needed to promote new bone growth, use of medications to improve bone density, and sometimes for postmenopausal women, use of hormone therapy." (WebMd, 2009)
Panicle	"Inflorescence where several small flowers branch from the same stem." (1998)
Pasting properties	"Functional properties relating to the ability of an item to act in a paste-like manner. Pasting properties of starch, e.g. gelatinization temperature, transparency, viscosity and retrogradation, have an important effect on the cooking and processing of foods."

(Service and The International Food, 2005)

Pentosans "Polysaccharides of five-carbon sugars (pentoses). Widely distributed in plants, e.g. fruit, wood, corncobs, oat hulls. Not digested in the body, and hence a component of non-starch polysaccharides and dietary fiber." (Bender 2005)

Polysaccharides "Complex carbohydrates formed by the condensation of large numbers of monosaccharide units, e.g. starch, glycogen, cellulose, dextrins, inulin. On hydrolysis the simple sugar is liberated." (Bender 2005)

Prolamins "The simple proteins, gliadin from wheat, zein from maize, hordein from barley, which are all insoluble in water or salt solutions, but are soluble in 70-80 percent alcohol." (Daniel, 1971)

Proline "A non-essential amino acid." (Bender 2005)

Rheology "The science of the study of plasticity and brittleness of such materials as fat, dough, casein, paste, etc." (Daniel 1971)

Salt "The scientific name for the substance produced when an acid acts upon a base, the metal of the latter displacing the hydrogen of the acid. Salt has an astringent action on gluten if used in reasonable quantities, but a larger quantity acts as a gluten solvent. Similarly, a very small amount of salt has beneficial effect on yeast action, but in only slightly greater amounts it retards fermentation whilst large quantities stop it altogether, hence the preservative properties of salt." (Daniel 1971)

Spikelet "Part of the flower head of plants such as grass, attached to the main stem without a stalk." (1998)

Sponge-dough method "Elements of the processes are similar to those for bulk fermentation in that a prolonged period of fermentation is required to effect physical and chemical changes in the dough. In this case only part of the ingredients are fermented – the sponge. Sponge fermentation times may vary considerably, as may their compositions. The key features of the sponge and dough processes are: (1) A two-stage process in which part of the total quantity of flour, water and other ingredients from the formulation are moxed to form an homogenous soft dough – the sponge; (2) The resting of the sponge so formed, in bulk for a prescribed time (floortime), mainly depending on flavor requirements; (3) Mixing of the sponge with the remainder of the ingredients to form an homogenous dough; and (4) Immediate processing of the final dough, although a short period of bulk fermentation may be given." (International Food Information, 2005)

Spread factor "A measurement used to define cookie quality and is the ratio of width to thickness (W/T)." (AACC International, 2009)

Starch "Polysaccharide, a polymer of glucose units; the form in which carbohydrate is stored in the plant; it does not occur in animal tissue. Starch is broken down by acid or enzymic hydrolysis, or during digestion, first to maltose and then glucose; it is the principal carbohydrate of the diet and hence the major source of energy. Starches from different sources have different structures, and contain different proportions of two major forms: amylose, which is a linear polymer and amylopectin, which has a branched structure." (Bender 2005)

Starch, pregelatinized "Raw starch does not form a paste with cold water and therefore requires cooking if it is to be used as a food thickening agent." (Bender, 2005)

Straight-dough method "A method of making bread in which all the ingredients are blended at one operation to form a dough which, after the appropriate period of fermentation, is divided, molded, proved, and baked. In the process no pre-fermentation is used as is the case with doughs mixed with a sponge or ferment." (Daniel 1971)

Sucrose "Cane or beet sugar. A disaccharide composed of glucose and fructose." (Bender, 2005)

Sugar "Commonly table sugar or sucrose, which is extracted from the sugar beet or sugar cane, concentrated, and refined. Molasses is the residue left after the first stage of crystallization and is bitter and black. The residue from the second stage is treacle, less bitter and viscous than molasses. The first crude crystals are Muscovado or Barbados sugar, brown and sticky. The next stage is light brown, Demerara sugar. Refined white sugar is essentially 100% pure sucrose. Soft sugars are fine-grained and moister, white or brown. Chemically a group of carbon, hydrogen, and oxygen (carbohydrates). The simplest sugars are monosaccharides. They may contain three (triose), four (tetrose), five (pentose), six (hexose), or seven (heptose) carbon atoms, with hydrogen and oxygen in the ratio of $C_n:H_{2n}:O_n$. The nutritionally important monosaccharides are hexoses: glucose, fructose, and galactose." (Bender 2005)

Surfactants "Surface active agents; compounds that have an affinity for fats (hydrophobic) and water (hydrophilic) and so act as emulsifiers, e.g. soaps and detergents." (Bender 2005)

Terminal "Referring to a shoot or bud at the end of a shoot." (1998)

Testa "The seed coat, an outer layer surrounding a seed and protecting the embryo inside." (1998)

Thresh "To separate grains from stalks and the seedheads of plants, in wheat and rye, the chaff is easily removed from the grain; in barley, only the awns are removed." (1998)

Threshing Machine "Machine formerly used to thresh cereals, now replaced by the combine harvester." (1998)

Tryptophan "An essential amino acid. In addition to its role in protein synthesis, it is the precursor of the neurotransmitter serotonin and of niacin." (Bender 2005)

Yeast "There are many kinds of yeasts but the baker is now only interested in pure culture bakers' yeast, specifically grown in yeast factories for bakers' use. Seen under the microscope yeast appears as single cells, round or slightly oval in shape, and exhibiting a vacuole and nucleus. Placed into a suitable medium containing all the foods needed, yeast cells commence to increase by the process of budding, thus bringing into existence completely new cells similar in every way to the parent cells." (Daniel 1971)

Viscosity "Stickiness. The resistance shown by a fluid to flow. The internal friction or power of resisting a change in the arrangement of the molecules or even of a change of shape or position." (Daniel 1971)

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Appendix A

Representation of Color Solid for L*a*b* Color Space

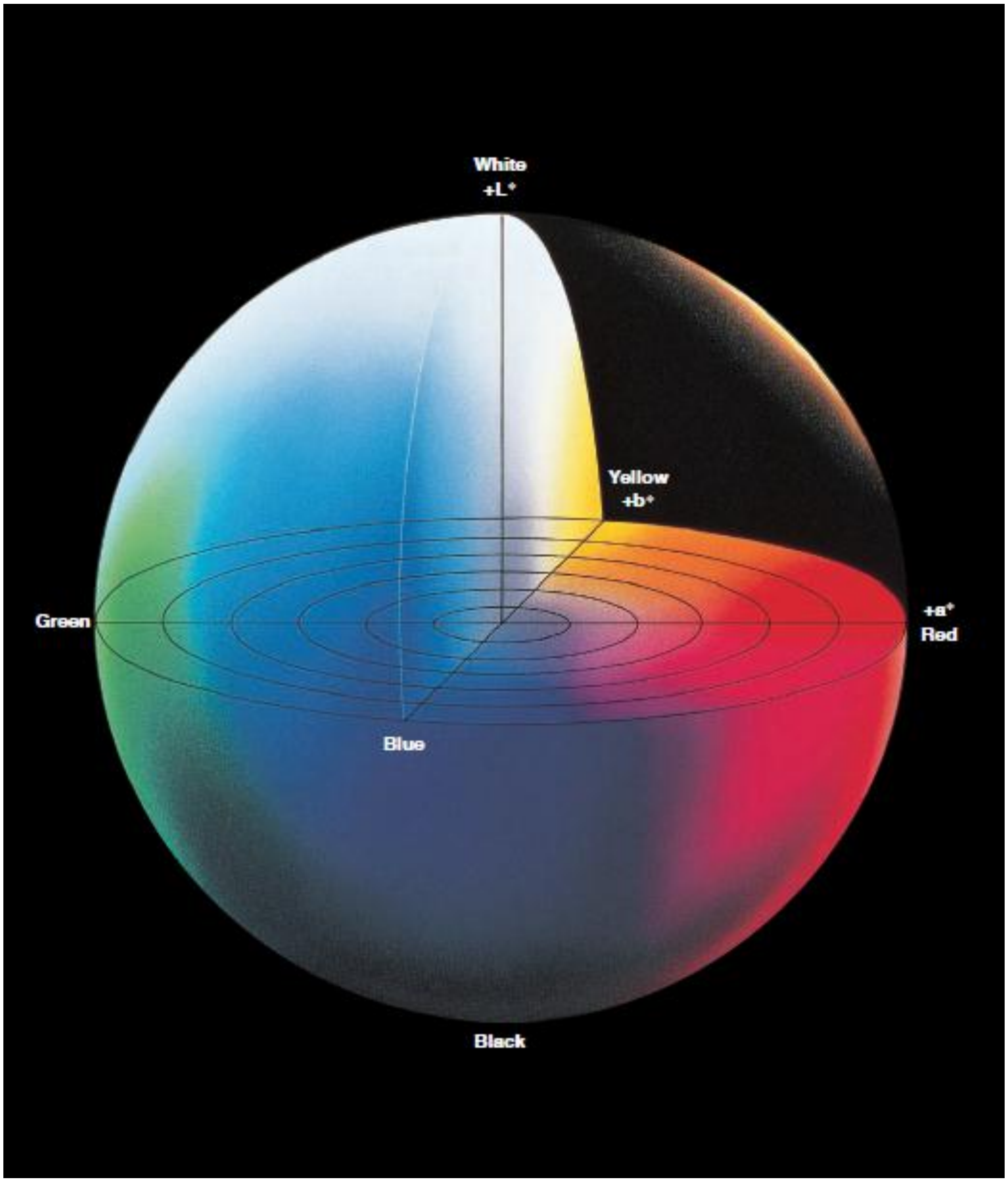

Figure 33. Representation of color solid for L*a*b* color space

Appendix B

Baking Quality of Cake Flour

Objective

To evaluate cake-baking quality of soft wheat short milling extraction (patent) flour. The method utilizes a high-ratio (more sugar than flour) white layer cake formulation. Cake flours appropriate for producing high-ratio layer cakes often receive postmilling treatment to reduce flour particle size and are pretreated with chlorine gas to about 4.8 pH. The formulation uses variable water level that is optimized based on cake contour. Higher cake-baking quality is indicated by larger cake volume at the proper cake contour.

Apparatus

1. Electric mixer. Use standard beater furnished with mixer.
2. Flour sifter. Use an ordinary household sifter or equivalent.
3. Baking pans. Use layer pans constructed of 4xxxx tinned sheet steel with inside dimensions 20.3 cm (8 in.]); depth 3.8 cm (11/3 in.).
4. Baking oven. Oven should be of rotary or reel type, fired electrically or by gas, and capable of maintaining temperature range of ±2°. Oven baking surface should be level.

Procedure

Caution: Baking powder reactions are temperature-dependent; thus uniformity of room and ingredient temperatures is important for obtaining consistent results over several days of baking.

Formula and ingredient specifications

	Amounts	
Ingredient	*(g)*	*%(flour basis)*
Flour (14% moisture basis)	200	100
Sugar	280	140
Shortening	100	50
Nonfat dry milk	24	12
Dried egg whites	18	9
NaCl	6	3
Baking powder and water, see below		

1. Sugar. Baker's Special or equivalent in fine-granulated sucrose.
2. Shortening. Baker's hydrogenated emulsifier-type shortening. It should be plastic and workable at room temperature and be free of any undesirable color, odor, or flavor.

3. Milk. Use dried milk conforming to specifications for extra grade nonfat dry milk. Maximum analytical tolerances are: butterfat, 1.25%; moisture, 4.0%; titratable acidity, 0.15%; solubility index, 1.25 ml; bacterial estimate, 50,000/g; and scorched particles, Disc B (15.0 mg). It must be entirely free of lumps except those that break up under slight pressure. Product when reliquefied must have a sweet and desirable flavor.
4. Egg whites. Spray-dried, desugared egg-white solids, with or without whipping aid, and having moisture content between 6.0 and 7.5%. Protein content ($N \times 6.25$) should be at least 80%, as-is basis; pH 7.0 ± 0.5; reducing sugar 0.1% maximum.
5. Salt. Fine-granulated table or "flour" grade.
6. Baking powder. Baker's double-action, especially formulated for high-ratio cakes (MCP and SAPP recommended). Do not use if more than 6 months has elapsed since purchase. Weigh out required quantity on day baked. Follow schedule below to determine quantity to use. For alternative leavening formulation, see Note.
7. Water. Use distilled water only. Determine liquid tolerance by baking cakes at following levels: 250, 270, and 290 ml (plus water required to bring flour weight to 200 g), corresponding to 125, 135, and 145% absorption with respect to flour. If volume contour and texture score trends indicate optimum liquid level should be above or below those used, bake again at appropriate selected absorptions.

Method

1. Bring oven to baking temperature, and condition it by baking cake using scrap batter made from the above formula.
2. Combine all dry ingredients except shortening, and sift well. Transfer to mixing bowl, add shortening and 60% of water. Mix at low speed (Hobart) or stir speed (KitchenAid) for 0.5 min, scrape down, and mix at medium speed for 4 min. Add one-half of remaining water, mix at low speed (Hobart) or stir speed (KitchenAid) for 0.5 min, scrape down, and mix at medium speed (Hobart) or speed no. 2 (KitchenAid) for 2 min. Add remaining water, mix at low speed (Hobart) or stir speed (KitchenAid) for 0.5 min, scrape down, and mix at medium speed (Hobart) or speed no. 2 (KitchenAid) for 2 min.
3. Grease pans lightly with commercial pan grease (1st choice) or nonemulsified shortening (2nd choice). Line bottom with parchment paper. Scale 425 g batter into each of two pans and bake at 190° (375° F; 1st choice) or 176° (350° F; 2nd choice) until done.
4. Cool cakes in pans for about 30 min, remove from pans, and continue cooling. Dust lightly with flour before measuring. If volume determination and texture scoring are to be delayed for more than 4 hr, dust cake lightly with flour and wrap with polyvinyl chloride film or equivalent material at time of depanning. Remove wrapping and redust for volume determination and scoring.Cakes should be graded for volume and texture on same day as baked.

Scoring

Obtain volumes of cakes by rapeseed displacement or by plastic measuring template, Method **10-91.01**. Compute mean volume of two layers. Grade internal texture according to Table I or equivalent.

Table 18. Scores for cake internal texture

TABLE I
Scores for Cake Internal Texture

Internal Factors (100 points)		Score (Points)
A. CELLS (30 points)		
1. Uniformity (10 points)	(a) Even (normal)	10
	(b) Slightly uneven	6
	(c) Uneven	2
2. Size (10 points)	(a) Dense (normal)	10
	(b) Close	8
	(c) Slightly open	6
	(d) Open	4
3. Thickness of walls (10 points)	(a) Thin (normal)	10
	(b) Slightly thick	6
	(c) Thick	2
B. GRAIN (16 points)		
1. Silky (normal)		16
2. Harsh		10
3. Coarse (corn bread)		8
C. TEXTURE (34 points)		
1. Moistness (10 points)	(a) Moist (normal)	10
	(b) Slightly dry	8
	(c) Gummy	6
	(d) Dry	4
2. Tenderness (14 points)	(a) Very tender (normal)	14
	(b) Tender	12
	(c) Slightly tough	10
	(d) Tough	4
3. Softness (10 points)	(a) Soft (normal)	10
	(b) Slightly firm	8
	(c) Firm	4
D. CRUMB COLOR (10 points)		
1. Bright white (normal)		10
2. White		8
3. Slightly dull		8
4. Slightly creamy		8
5. Creamy		6
6. Slightly dull and slightly creamy		4
E. FLAVOR (10 points)		
1. Normal (no off-flavor due to flour)		10
2. Foreign		0

Table 19. Adjustment of commercial leavening quantity to laboratory elevation and daily variations in barometric pressure

TABLE II
Adjustment of Commercial Leavening Quantity to Laboratory Elevation and Daily Variations in Barometric Pressure

Laboratory Elevation		Barometric Pressure on Day of Bake Corrected to Sea Level (inches Hg)									
		30.72–30.40		30.40–30.08		30.08–29.76		29.76–29.44		29.44–29.12	
(m)	(ft)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
0–12	0–39	14.0	7.00	13.5	6.75	13.0	6.50	12.5	6.25	12.0	6.00
12–43	39–141	13.5	6.75	13.0	6.50	12.5	6.25	12.0	6.00	11.5	5.75
43–92	141–302	13.0	6.50	12.5	6.25	12.0	6.00	11.5	5.75	11.0	5.50
92–160	302–525	12.5	6.25	12.0	6.00	11.5	5.75	11.0	5.50	10.5	5.25
160–247	525–810	12.0	6.00	11.5	5.75	11.0	5.50	10.5	5.25	10.0	5.00
247–353	810–1158	11.5	5.75	11.0	5.50	10.5	5.25	10.0	5.00	9.5	4.75
353–478	1158–1568	11.0	5.50	10.5	5.25	10.0	5.00	9.5	4.75	9.0	4.50
478–621	1568–2037	10.5	5.25	10.0	5.00	9.5	4.75	9.0	4.50	8.5	4.25
621–783	2037–2569	10.0	5.00	9.5	4.75	9.0	4.50	8.5	4.25	8.0	4.00
783–964	2569–3163	9.5	4.75	9.0	4.50	8.5	4.25	8.0	4.00	7.5	3.75
964–1164	3163–3819	9.0	4.50	8.5	4.25	8.0	4.00	7.5	3.75	7.0	3.50
1164–1382	3819–4534	8.5	4.25	8.0	4.00	7.5	3.75	7.0	3.50	6.5	3.25
1382–1620	4534–5315	8.0	4.00	7.5	3.75	7.0	3.50	6.5	3.25	6.0	3.00
1620–1876	5315–6155	7.5	3.75	7.0	3.50	6.5	3.25	6.0	3.00	5.5	2.75

Volume, contour, and score maxima are sometimes obtained at different liquid levels. When such occurs, select cake that most nearly represents desired performance objectives.

Note

If baking powder described in **Procedure**, step 6, is not available in fresh condition, a laboratory-prepared substitute may be used as follows:

a. Determine required baking powder level in grams or percents from Table II for your altitude and barometric pressure.
b. Let X = percent or gram.
c. Use 0.3X for sodium bicarbonate, fine granular, $NaHCO_3$; 0.05X for monocalcium phosphate, monohydrate, $Ca(H_2PO_4)_2 \cdot H_2O$ (MCP); and 0.36X for sodium acid pyrophosphate, $Na_2H_2P_2O_7$ (SAPP, baking powder grade according to supplier).

Appendix C

Baking Quality of Cookie Flour

Objective

In North America, “cookie” is a product similar to what is internationally known as “biscuit”. Cookie quality is determined (in six cookies) by width (W), thickness (T), and W/T ratio (cookie spread factor), which adjustments to constant atmospheric pressure and conditions. The formulation uses 225 g of flour, a mixing bowl and paddle, and a fixed amount of water added to dough. Dextrose is used to aid in developing brown color. This method predicts the general quality of soft wheat flour for production of contemporary cookie and pastry products (except cake and crackers). High quality of pastry flour is usually associated with larger sugar-snap cookie diameter. This method is also useful to evaluate other flour types, various flour treatments, and other factors, such as ingredients, that affect cookie geometry.

Apparatus

1. Electric mixer, with flat beater.
2. Aluminum cookie sheet, 3003-H14 aluminum alloy, 2.032 mm (0.080 in) thickness, size 30.5 x 40.6 cm (12 x 16 in) or 25.4 x 33.0 cm (10 x 13 in), or other sizes required to accommodate oven doors and shelves. See Note 1.
3. Metal gauge strips, two, 7 mm (0.275 in) thick and length of baking sheets. Strips can be attached to long edges of sheets. Strips should be kept clean of any buildup of grease residue. See Note 1.
4. Rolling pin, 5.7-7.0 cm (2.25-2.75 in) diameter covered with No. 3 size surgical seamless, tubular gauze or equivalent covering. If wood, check often for any wear to edges from rolling along gauge strips.
5. Cookie cutter, 60 mm (nearly ¼ in) inside diameter. See Note 1.
6. Baking oven, reel or rotary, with hearth consisting of ceramic-fiber-reinforced structural alumina refractory product (0.64 cm thick) as shelf liner cut to dimensions of and placed on steel baking shelf. Oven shelves consisting of wire mesh baking surface are also suitable and may not need shelf liner (to prevent excessive bottom browning). Oven should be electrically heated and capable of maintaining temperature range of ± 2 at 205° (± 5 at 400°F).
7. Barometer and room temperature (see Note 2).

Procedure

Formula

Ingredients, at 23.9° (75°F)	*Weight (g)*
Shortening (see Note 3)	64.0
Sugar (see Note 4)	130.0
NaCl	2.1
Sodium bicarbonate	2.5
Dextrose solution (8.9 g dextrose hydrous, USP in 150 ml water)	33.0
Distilled water (see Note 5, Table I)	16.0
Flour, 14% moisture basis (see Note 5, Table I)	225.0

Method

1. Cream shortening, sugar, salt, and sodium bicarbonate on low speed or stir speed 3 minutes. Scrape down after each minute.
2. Add dextrose solution and distilled water. Mix 1 minute at low speed or stir speed. Scrape. Mix 1 minute at medium speed or speed no. 2. Add all flour an dmix 2 minutes at low speed or stir speed, scraping down after each ½ minute.
3. Gently scrape dough from bowl and place six portions of dough at well-spaced points on lightly greased cookie sheet. See Note 6. Flatten dough mounds lightly with palm of hand. Using gauge strips, roll to thickness with one forward rolling pin stroke and one return (backward) stroke. Cut dough with cookie cutter, discard excess dough, and remove cutter. See Note 6.

Table 20. Calculated amounts of flour and water for cookie test formula

Table I Calculated Amounts of Flour and Water for Cookie Test Formula					
Flour Moisture (%)	Distilled Water (ml)	Flour (g)	Flour Moisture (%)	Distilled Water (ml)	Flour (g)
9.0	28.4	212.6	11.7	21.9	219.1
9.1	28.1	212.9	11.8	21.6	219.4
9.2	27.9	213.1	11.9	21.4	219.6
9.3	27.7	213.3	12.0	21.1	219.9
9.4	27.4	213.6	12.1	20.9	220.1
9.5	27.2	213.8	12.2	20.6	220.4
9.6	27.0	214.0	12.3	20.4	220.6
9.7	26.7	214.3	12.4	20.1	220.9
9.8	26.5	214.5	12.5	19.9	221.1
9.9	26.2	214.8	12.6	19.6	221.4

10.0	26.0	215.0	12.7	19.4	221.6
10.1	25.8	215.2	12.8	19.1	221.9
10.2	25.5	215.5	12.9	18.8	222.2
10.3	25.3	215.7	13.0	18.6	222.4
10.4	25.0	216.0	13.1	18.3	222.7
10.5	24.8	216.2	13.2	18.1	222.9
10.6	24.6	216.4	13.3	17.8	223.2
10.7	24.3	216.7	13.4	17.6	223.4
10.8	24.1	216.9	13.5	17.3	223.7
10.9	23.8	217.2	13.6	17.1	223.9
11.0	23.6	217.4	13.7	16.8	224.2
11.1	23.6	217.7	13.8	16.5	224.5
11.2	23.1	217.9	13.9	16.3	224.7
11.3	22.8	218.2	14.0	16.0	225.0
11.4	22.6	218.4	14.1	15.7	225.3
11.5	22.4	218.6	14.2	15.5	225.5
11.6	22.1	218.9	14.3	15.2	225.8

4. Get dough weight and bake immediately (see Note 7).
5. Bake cookies 10 minutes at 205° (400°F) (see Note 8).
6. On removal from oven, lift cookies from baking sheet with nonstick coated utensil. Wipe baking sheet with damp towel to remove grease. Wash in warm non-soapy water, dry thoroughly, and allow to come to room temperature before next use. See Note 1.

Multiple quantities of shortening, sugar, salt, and soda may be precreamed per step 1 for a 1-day bake series. Scale 198.6 g premix and proceed on at step 2.

Calculations

After cooling for 30 minutes, lay cookies edge to edge and measure width. Rotate them 90° and remeasure to obtain average width (W) of six cookies in mm.

Table 21. Correction factors for adjusting W/T (as-is) to constant atmospheric pressure basis

Table II Correction Factors for Adjusting W/T (as-is) to Constant Atmospheric Pressure Basis							
Laboratory	Barometric Pressure – inches of Hg (Corrected to Sea Level)						
Elevation (feet above seas level)	29.31 to 29.50	29.51 to 29.70	29.71 to 29.90	29.91 to 30.10	30.11 to 30.30	30.31 to 30.50	30.51 to 30.70
0-100	0.982	0.988	0.994	1.000	1.006	1.012	1.018
101-300	0.976	0.982	0.988	0.994	1.000	1.006	1.012
301-500	0.970	0.976	0.982	0.988	0.994	1.000	1.006
501-700	0.964	0.970	0.976	0.982	0.988	0.994	1.000
701-900	0.958	0.964	0.970	0.976	0.982	0.988	0.994

901-1100	0.952	0.958	0.964	0.970	0.976	0.982	0.988
1101-1300	0.946	0.952	0.958	0.964	0.970	0.976	0.982
1301-1500	0.940	0.946	0.952	0.958	0.964	0.970	0.976
1501-1700	0.934	0.940	0.946	0.952	0.958	0.964	0.970
1701-1900	0.928	0.934	0.940	0.946	0.952	0.958	0.964
1901-2100	0.923	0.928	0.934	0.940	0.946	0.952	0.958
2101-2300	0.917	0.923	0.928	0.934	0.940	0.946	0.952
2301-2500	0.911	0.917	0.923	0.928	0.934	0.940	0.946
2501-2700	0.905	0.911	0.917	0.923	0.928	0.934	0.940
2701-2900	0.899	0.905	0.911	0.917	0.923	0.928	0.934
2901-3100	0.893	0.899	0.905	0.911	0.917	0.923	0.928
3101-3300	0.887	0.893	0.899	0.905	0.911	0.917	0.923
3301-3500	0.881	0.887	0.893	0.899	0.905	0.911	0.917
3501-3700	0.875	0.881	0.887	0.893	0.899	0.905	0.911
3701-3900	0.869	0.875	0.881	0.887	0.893	0.899	0.905
3901-4100	0.863	0.869	0.875	0.881	0.887	0.893	0.899
4101-4300	0.857	0.863	0.869	0.875	0.881	0.887	0.893
4301-4500	0.851	0.857	0.863	0.869	0.875	0.881	0.887
4501-4700	0.845	0.851	0.857	0.863	0.869	0.875	0.881
4701-4900	0.839	0.845	0.851	0.857	0.863	0.869	0.875
4901-5100	0.833	0.839	0.845	0.851	0.857	0.863	0.869

Stack cookies one on top of another and measure thickness. Restack in different order and remeasure to get average thickness (T) of six cookies in mm. Read to nearest ½ mm for these measurements. Divide by six to obtain W (as-is) and T (as-is). Using correction factor (CF), calculate adjusted W, T, and W/T ratio (spread factor) as follows:

Width (W) divided by thickness (T) is W/T ratio (as-is)
W/T (as-is) x CF = adjusted W/T. See Note 9, Table II.
Adjusted W/T x 10 = spread factor
W (as-is) x CF = adjusted W. See Note 9, Table III.
T (as-is) x CF = adjusted T. See Note 9, Table IV.

Width is recommended as the most sensitive and reliable estimate of flour quality. Width and, in some cases, thickness of cookies are better estimates of flour quality than in W/T ratio (spread factor) because it is a ratio of two measured parameters. Both width and thickness could vary such that several widths and thicknesses could give the same spread factor.

Table 22. Correction factors for adjusting W/T (as-is) to constant atmospheric pressure basis

Table III Correction Factors for Adjusting W/T (as-is) to Constant Atmospheric Pressure Basis							
Laboratory	Barometric Pressure – inches of Hg (Corrected to Sea Level)						
Elevation (feet above seas level)	29.31 to 29.50	29.51 to 29.70	29.71 to 29.90	29.91 to 30.10	30.11 to 30.30	30.31 to 30.50	30.51 to 30.70
0-100	0.993	0.995	0.997	1.000	1.002	1.005	1.007
101-300	0.990	0.993	0.995	0.997	1.000	1.002	1.005
301-500	0.988	0.990	0.993	0.995	0.997	1.000	1.002
501-700	0.986	0.988	0.990	0.993	0.995	0.997	1.000
701-900	0.983	0.986	0.988	0.990	0.993	0.995	0.997
901-1100	0.981	0.983	0.986	0.988	0.990	0.993	0.995
1101-1300	0.978	0.981	0.983	0.986	0.988	0.990	0.993
1301-1500	0.976	0.978	0.981	0.983	0.986	0.988	0.990
1501-1700	0.974	0.976	0.978	0.981	0.983	0.986	0.988
1701-1900	0.971	0.974	0.976	0.978	0.981	0.983	0.986
1901-2100	0.969	0.971	0.974	0.976	0.978	0.981	0.983
2101-2300	0.976	0.969	0.971	0.974	0.976	0.978	0.981
2301-2500	0.964	0.976	0.969	0.971	0.974	0.976	0.978
2501-2700	0.962	0.964	0.976	0.969	0.971	0.974	0.976
2701-2900	0.959	0.962	0.964	0.976	0.969	0.971	0.974
2901-3100	0.957	0.959	0.962	0.964	0.976	0.969	0.971
3101-3300	0.955	0.957	0.959	0.962	0.964	0.976	0.969
3301-3500	0.952	0.955	0.957	0.959	0.962	0.964	0.976
3501-3700	0.950	0.952	0.955	0.957	0.959	0.962	0.964
3701-3900	0.948	0.950	0.952	0.955	0.957	0.959	0.962
3901-4100	0.945	0.948	0.950	0.952	0.955	0.957	0.959
4101-4300	0.943	0.945	0.948	0.950	0.952	0.955	0.957
4301-4500	0.941	0.943	0.945	0.948	0.950	0.952	0.955
4501-4700	0.939	0.941	0.943	0.945	0.948	0.950	0.952
4701-4900	0.936	0.939	0.941	0.943	0.945	0.948	0.950
4901-5100	0.934	0.936	0.939	0.941	0.943	0.945	0.948

Notes

1. Cookie sheets, are purchased with gauge strips fastened to the long edges of sheets. New cookie sheets may be conditioned by lightly greasing and placing in hot oven for 15 minutes, cooling, and repeating process two or three more times. Cookie sheets should be washed while warm in water (without any soaps or detergents) and wiped dry after each bake to prevent buildup and blackening of soil on their surface.

2. Cookie dough by mixing efficiency and resulting cookie size are influenced by ingredient, dough, and room temperature. Consistent temperature is critical to consistent baking results.

Table 23. Correction factors for adjusting W/T (as-is) to constant atmospheric pressure basis

Table IV Correction Factors for Adjusting W/T (as-is) to Constant Atmospheric Pressure Basis							
Laboratory	Barometric Pressure – inches of Hg (Corrected to Sea Level)						
Elevation (feet above seas level)	29.31 to 29.50	29.51 to 29.70	29.71 to 29.90	29.91 to 30.10	30.11 to 30.30	30.31 to 30.50	30.51 to 30.70
0-100	1.013	1.008	1.004	1.000	0.996	0.992	0.987
101-300	1.017	1.013	1.008	1.004	1.000	0.996	0.992
301-500	1.021	1.017	1.013	1.008	1.004	1.000	0.996
501-700	1.025	1.021	1.017	1.013	1.008	1.004	1.000
701-900	1.030	1.025	1.021	1.017	1.013	1.008	1.004
901-1100	1.034	1.030	1.025	1.021	1.017	1.013	1.008
1101-1300	1.038	1.034	1.030	1.025	1.021	1.017	1.013
1301-1500	1.042	1.038	1.034	1.030	1.025	1.021	1.017
1501-1700	1.047	1.042	1.038	1.034	1.030	1.025	1.021
1701-1900	1.051	1.047	1.042	1.038	1.034	1.030	1.025
1901-2100	1.055	1.051	1.047	1.042	1.038	1.034	1.030
2101-2300	1.059	1.055	1.051	1.047	1.042	1.038	1.034
2301-2500	1.064	1.059	1.055	1.051	1.047	1.042	1.038
2501-2700	1.068	1.064	1.059	1.055	1.051	1.047	1.042
2701-2900	1.072	1.068	1.064	1.059	1.055	1.051	1.047
2901-3100	1.076	1.072	1.068	1.064	1.059	1.055	1.051
3101-3300	1.081	1.076	1.072	1.068	1.064	1.059	1.055
3301-3500	1.085	1.081	1.076	1.072	1.068	1.064	1.059
3501-3700	1.089	1.085	1.081	1.076	1.072	1.068	1.064
3701-3900	1.093	1.089	1.085	1.081	1.076	1.072	1.068
3901-4100	1.009	1.093	1.089	1.085	1.081	1.076	1.072
4101-4300	1.102	1.009	1.093	1.089	1.085	1.081	1.076
4301-4500	1.106	1.102	1.009	1.093	1.089	1.085	1.081
4501-4700	1.110	1.106	1.102	1.009	1.093	1.089	1.085
4701-4900	1.114	1.110	1.106	1.102	1.009	1.093	1.089
4901-5100	1.119	1.114	1.110	1.106	1.102	1.009	1.093

3. Shortening should be hydrogenated, all-vegetable fat of nonemulsifier type, not containing methyl silicone, and having medium consistency. It should have approximately the following solid fat index (SFI) profile as determined by the dilatometric method:

Temperature (°C)	*SFI*
10.0	28-33
21.1	18-22
33.3	11-16
40.0	8-12

4. Only through of U.S. No. 30 wire sieve (600-µm openings) of any brand of granulated sugar should be used.
5. Amounts of flour and water to be used depend on flour moisture and are taken from Table I.
6. Operators should wash their hands to remove any hand creams and should avoid excessive handling of dough.
7. Dough weight in g is obtained by subtracting weight of cookie sheet from weight shown after six cookies dough pieces have been cut on sheet. It is useful for comparing relative dough density between batches and is related to weight of baked cookies.
8. Oven should be warmed to temperature with oven shelves turning. Bake “dummy” cookies out of scrap dough and extra flour to condition over before making test bake at beginning of baking series or if oven has not been used for 15 minutes.
9. Correction factor to be applied depend on laboratory elevation and barometric pressure reading corrected to seal level existing when test cookies are baking. Correction factor for W/T is taken from Table II. Correction factor for W is taken from Table III. Correction factor for T is taken from Table IV.

Appendix D

Baking Quality of Biscuit Flour

Objective

To evaluate soft wheat flour when used to produce chemically leavened (bread type) biscuits. IN the United States, “biscuit” refers to small chemically leavened breads, sometimes known as “baking powder biscuits,” the flour for which may be pretreated with specific leavening agents. Portions (milling streams) of soft wheat flours for use in baking chemically leavened biscuits are often treated with chlorine gas to improve biscuit thickness and control spreading during baking. Self-rising flours containing chemical leavening agents can be evaluated by omitting leavening ingredients and salt. The method is not applicable to cookies.

Apparatus

1. Electric mixer, with timer control, equipped with appropriate flat beaters furnished with mixer.
2. Aluminum cookie sheet, 14-gauge, 2S-H14 aluminum allows, 30.5 x 40.6 cm (12 x 16 in) size with two metal gauge strips 7 mm (0.275 in) thick and 38 cm (15 in) long attached to long edges. See Note 1.
3. Rolling pin, with diameter of 5.7 x 7.0 cm (2.25 -2.75 in).
4. Biscuit cutter, 5.1-cm (2-in) inside diameter.
5. Wooden rolling board.
6. Wooden gauge sticks, two, flat, 1.27 cm (1/2 in) thick. (They can be attached to rolling board, parallel, and at a distance apart appropriate for rolling pin length).
7. Baking over, reel or rotary, with hearth consisting of 30.5 x 40.6 cm (12- x 16-in) section of pressed asbestos sheet 0.64 cm (1/4 in) thick placed on steel plate 0.32 cm (1/8 in) thick of same dimensions. Over should be electrically heated and capable of maintaining temperature range of ± 2° at 205° (± 5° 400°F).

Procedure

Formula (per batch)

Ingredients at 21 ± 1° (70 ± 2°F) except milk solution	*Weight (g)*
Flour (14% moisture basis, see Table 1)	228.0
All-purpose shortening (See Note 2)	40.0
Milk solution at 4 ± 2° (39 ± 4°F) (See Note 3)	135.0
NaCl*	4.5
Sodium bicarbonate*	3.4
Monocalcium phosphate, monohydrate*	4.1

*Omit is self-rising flour is used; then use 240.0 g of self-rising flour

Method

1. Sift together flour and other dry ingredients (sodium bicarbonate, monocalcium phosphate, and salt, if used) into mixing bowl.
2. Add shortening to flour mixture. Mix at speed 1 or stir speed for 15 seconds. Scrape bowl and blade. Mix at speed 1 or at stir speed for 3 minutes. When done, mixture should have clumps about 0.2-0.5 cm in diameter.
3. Scrape bowl and beater. Add milk solution and mix at speed 1 or stir speed for 15 seconds.
4. Scrape dough onto lightly floured rolling bord.
5. With floured rolling pin, roll out dough from center to edges using gauging sticks. Fold dough into thirds perpendicular to long dimensions. Turn dough 90° and place dough, folded side down, on floured surface such that folded edges are parallel to gauge strips and reroll.
6. Cut dough with floured cutter by pressing down into dough. Do not twist cutter.
7. Place eight dough pieces 4 cm apart on ungreased baking sheet.
8. Immediately place in 232° (450°F) oven for 10 minutes. See Note 4. Remove biscits from baking sheet upon removal from oven.
9. After 30 minutes, make following measurements:

Table 24. Weights of flour at various moisture contents corresponding to 228 g flour weight at 14% moisture basis

Table I
Weights of Flour at Various Moisture Contents Corresponding to 228 g Flour Weight at 14% Moisture Basis

Flour Moisture (%)	Flour Weight (g)	Flour Moisture (%)	Flour Weight (g)	Flour Moisture (%)	Flour Weight (g)
10.0	217.9	11.7	222.1	13.4	226.4
10.1	218.1	11.8	222.3	13.5	226.7
10.2	218.4	11.9	222.6	13.6	226.9
10.3	218.6	12.0	222.8	13.7	227.2
10.4	218.8	12.1	223.1	13.8	227.5
10.5	219.1	12.1	223.3	13.9	227.7
10.6	219.3	12.3	223.6	14.0	228.0
10.7	219.6	12.4	223.8	14.1	228.3
10.8	219.8	12.5	224.1	14.2	228.5
10.9	220.1	12.6	224.3	14.3	228.8
11.0	220.3	12.7	224.6	14.4	229.1
11.1	220.6	12.8	224.9	14.5	229.3
11.2	220.8	12.9	225.1	14.6	229.6
11.3	221.1	13.0	225.4	14.7	229.9
11.4	221.3	13.1	225.6	14.8	230.1

11.5	221.6	13.2	225.9	14.9	230.4
11.6	221.8	13.3	226.2	15.0	230.6

a. total weight of eight biscuits (to 0.01 g)
b. total diameter of eight biscuits, turning each biscuit three times to make three diameter measurements, and report mean of three measurements.
c. Height at top center of each biscuit; report total height of eight. Biscuit weights must be taken 30 ± 2 minutes after baking. During multiple bakes, height and width measurements may be delayed up to 3 hours.

Notes

1. New sheets may be broken in by lightly greasing and pacing in hot oven for 15 minutes.
2. Shortening should be hydrogenated, all-vegetable fat of nonemulsifier type, not containing methyl silicone.
3. To make milk solution, thoroughly dissolve 50 g milk powder in 450 ml distilled water.
4. Bake "dummy" biscuits out of scrap or extra dough to condition oven before making a test bake at the beginning of then baking series or if the oven has not been used for 15 minutes.

Appendix E

Sponge-Dough Method

Objective

This method provides a bread-baking test for assessing the quality of wheat flour by a sponge-dough method. It involves a two-step process. In the first step, the *sponge* is made by mixing part of the total flour with water, yeast, and yeast food. The sponge is allowed to ferment 4 hr. In the second step, the sponge is incorporated with the rest of the flour, water, and other ingredients to make *dough*. This method may also be used for wheat-based composite flours and for other ingredients that may affect loaf characteristics.

Apparatus

1. Baking pans for 1-lb loaves. Tinplate, 4X, unglazed; dimensions—top inside, about 22.9 × 11.4 cm (9 × 41/2 in.); bottom outside, about 21 × 9.5 cm (81/4 × 33/4 in.); inside depth, about 7 cm (23/4 in.).
2. Mixer, equipped with water-jacketed mixing bowl and fork (McDuffee type).
3. Fermentation cabinet, capable of maintaining constant temperature of 30 ± 1° (86 ± 2°F) at 85% relative humidity.
4. Fermentation bowls; 4-qt capacity.
5. Flour containers; 1-qt capacity with tight-fitting lids.
6. Loaf volumeter; seed displacement type.
7. Oven; reel or rotary, gas or electric, with level baking surfaces, and capable of temperature control to ±5° or less.
8. Proofing cabinet, capable of maintaining constant temperature of 35.5 ± 1° (96 ± 2°F) at 92% relative humidity.
9. Scales; balance having 1-kg capacity and 0.1 g sensitivity.
10. Sheeter and molder; 6-in. rolls.
11. Thermometers, capable of reading to 50° (approx. 120° F) with graduations in 0.1 or 0.2°. Either red-spirit-filled, pierce-type, or metal dial-type. Metal types should be tested frequently for accuracy.

Procedure

This method is based on use of total of 700 g of test flour.

Sponge

1. Formula:

	Amounts	
	(g)	*% (flour basis)*
Flour (14% moisture basis).	420.0	60.0

See Note 1		
Water (variable), See Note 2	252.0	36.0
Yeast, compressed. (For dry yeast, see Note 3)	14.0	2.0
Yeast food. See Note 4	3.5	0.5

2. Add all ingredients to mixer, and mix sponge 0.5 min in first speed and 1 min in second speed, or until smooth. Temperature of sponge after mixing: 26.5 ± 0.3° (80 ± 0.5°F). It may be necessary to adjust water temperature or mixing bowl jacket temperature to achieve proper sponge temperature.
3. Place sponge in fermentation bowl and set aside in fermentation cabinet for 4 hr at 30° (86°F).

Dough

1. Formula

	Amounts	
	(g)	*% (flour basis)*
Flour (14.0% moisture basis)	280.0	40.0
Water (variable). See Note 2	168.0	24.0
Sugar (sucrose)	35.0	5.0
Salt	14.0	2.0
Shortening, hydrogenated, vegetable	21.0	3.0

2. Place ingredient water in mixing bowl, add preweighed dry ingredients from flour can and shortening, and start mixer in first speed. Add sponge in three approximately equal portions at 15, 25, and 35 sec mixing time. Continue mixing in first speed until 1 min has elapsed from beginning of mixing.
3. Shift mixer into second speed and mix to optimum development (see Note 5), noting total time dough was mixed. Dough temperature out of mixer should be 27.0 ± 0.3° (81 ± 0.5°F), accomplished by adjusting ingredient temperatures in relation to ambient temperature and/or by adjusting mixing bowl jacket tem-perature.

Makeup

1. Recovery time. Round up dough lightly as it comes from mixer; place in lightly greased fermentation bowl, place bowl in fermentation cabinet, and leave for 30 min. See Note 6.
2. Sealing. After 30 min rest in fermentation cabinet, remove dough and divide into two 500-g dough pieces.
3. Intermediate proof. Round each piece lightly and place in fermentation cabinet. Allow 12–15 min in cabinet for relaxation before molding. See Note 6.

4. Sheeting and molding. Pass dough piece through sheeter twice. For first pass, set rolls at 5/16 in.; for second pass, set rolls at 3/16 in. Curl “as a ribbon,” seal, and elongate to 91/2 in., using molder. Place in lightly greased baking pan, seam down.

Proof

Place panned dough in proofing cabinet at 35.5° (96°F) and 92% relative humidity. Proof to template of 3/8 in. above top rim of pan.

Bake

Bake at 218° (425°F) for 25 min.

Score

1. Weigh loaf and determine volume with volumeter 1 hr after removal from oven. Record in g and cm3, respectively.
2. When loaf has cooled to internal temperature of 32° (90°F), wrap in waxed paper or place in plastic bag if bread is to be evaluated for factors other than loaf volume.
3. Score for external and internal characteristics 18 hr after baking.

Notes

1. Malted wheat or barley flour should be added only if the flour is deficient in diastatic activity. It is believed that no supplementation will be needed if the flour under test shows amylograph value of between 400 and 600 Brabender units.
2. Total absorption is determined by the test baker’s judgment. Information obtained from physical dough tests may provide direction. Refer to Methods **54-10.01**, **54-21.01**, or **54-40.02**. It may be desirable, in some cases, to bake a series of doughs at different levels of absorption. Whenever such a series is conducted, it is recommended that 2% absorption increments be used.
3. Follow the yeast manufacturer’s recommendations on rehydration, if using dry yeast.
4. Preblended yeast foods can be obtained from a variety of ingredient suppli-ers. Proper selection of yeast food may be dependent on local water conditions. Work with supplier to make appropriate choice.
5. Optimum mixing time for dough is determined by the test baker. Informa-tion obtained from physical dough tests may provide direction. Refer to Methods **54-10.01**, **54-21.01**, or **54-40.02**. It may be desirable, in some cases, to bake a series of doughs that have been mixed to differing degrees of development. In studies of this kind, mixing time increments should not be varied by more than 2 min.
6. Experienced operators may determine that doughs made from some types of flour respond favorably to slightly different recovery (and intermediate proof) time than outlined in this procedure.

Appendix F

Rosemary and Parmesan Teff Crackers

Nate Foust-Meyer, Jennifer Coleman, Amber Hickman

½ stick butter

2 sprigs rosemary

½ cup teff flour

½ cup all-purpose flour

¾ teaspoon salt

1 cup parmesan cheese

½ cup milk

- Pre-heat oven to 400°F
- Combine dry ingredients with butter to resemble bread crumbs
- Add milk incrementally until a loose dough has formed
- Roll out dough as thin as possible
- Slice into desired size
- Bake for about 20 minutes

Appendix G

Gluten-free Pizza Dough

Nate Foust-Meyer, Jennifer Coleman, Amber Hickman

1 cup teff

½ cup rice flour

½ cup tapioca flour

½ teaspoon salt

1 tablespoon canola oil

1 package yeast

200 mL water

1 teaspoon honey

- Add honey to yeast
- Mix ingredients in a bowl until dough pulls from the sides of the bowl
- Add more flour if too wet
- Roll out dough to desired thickness
- Add toppings
- Bake in oven at 425°F for 5-10 minutes