Nutritional and Functional Perspectives of Quinoa (*Chenopodium quinoa* L.)

By

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I hereby declare that the contents of the thesis, studies on “Nutritional and Functional Perspectives of Quinoa (Chenopodium quinoa L.)” are the product of my own research and no part has been copied from any published source (expect the references, standard mathematical or genetic models/equations/formulas/protocols etc). I, further, declare that this work has not been submitted for the award of any other diploma/degree. The university may take action if the information provided found inaccurate at any stage. (In case of any default the scholar will be proceeded against as per HEC plagiarism policy).

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ABSTRACT

The core objective of the current research is to characterize different lines of quinoa for their nutritional profile and fatty acid composition. For the purpose quinoa lines were procured from Department of Crop Physiology, University of Agriculture Faisalabad-Pakistan and were analyzed for their different characteristics. Results showed that the moisture content, ash content, fat content, fiber content and total starch content ranged from 9.74±0.22 to 10.62±0.24%, 2.18±0.08 to 2.80±0.02%, 3.57±0.11 to 7.97±0.12%, 11.00±0.34 to 16.08±0.02%, 1.99±0.12 to 3.52±0.18% and 53.43±0.23 to 63.15±0.92%, respectively. In addition, potassium, calcium, magnesium, manganese, sodium, sulphur, phosphorous, Zinc, Boron, and copper ranged from 8497.08±51.97 to 9443.41±114.7, 578.35±4.53 to 669.45±5.20, 2058.1±28.28 to 2173.4±23.12, 30.66±0.21 to 35.28±0.12, 24.58±0.29 to 62.81±0.52, 1499.21±9.30 to 1606.30±8.29, 4491.6±20.78 to 4560.0±16.16, 24.30±0.22 to 32.12±0.52, 15.29±0.05 to 17.04±0.07 and 4.01±0.02 to 5.04±0.06 mg/kg, respectively. Furthermore, the fatty acid profile (%) of quinoa oil was as palmitic acid (11.39±0.02 to 13.25±0.30), oleic acid (26.28±0.15 to 31.62±0.14), Linoleic acid (47.79±0.19 to 52.02±0.54), α-Linolenic acid (4.45±0.03 to 7.71±0.06), and erucic acid (1.41±0.01 to 1.74±0.00). Furthermore, bread was prepared from composite flour by substituting wheat with quinoa flour at 5%, 10%, 15% and 20%, result showed significant increase in ash, protein and fiber content of bread, ash ranged from 1.47±0.007 to 1.62±0.017%, protein 11.28±0.032 to 11.63±0.107% and fiber ranged from 1.31±0.014 to 1.52±0.040%. Results showed that the functional properties i.e. water absorption capacity of quinoa protein isolates ranged from 2.81±0.17-3.82±0.05%, oil absorption capacity from 2.72±0.02 to 3.03±0.03% and foaming capacity from 9.09±0.05 to 10.05±0.07%. Moreover, the in-vitro digestibility ranged from 75.95±0.29 to 78.11±0.43%. In addition, quinoa have protein efficiency ratio in the range of 3.50±0.04 to 3.78±0.05, net protein ratio ranged from 3.90±0.04 to 4.69±0.05, net protein utilization from 70.75±0.86 to 73.78±0.89, biological value from 79.15±0.96 to 81.74±0.99 and true digestibility from 87.66±1.06 to 90.57±1.10. Conclusively, results showed that quinoa lines grown in Pakistan has strong nutritional profile and fatty acid composition.
CHAPTER 1

INTRODUCTION

Since times immemorial, phytochemicals are believed to endorse certain health enhancing perspectives. Moreover, these plant bioactives are also known to impart certain quality and sensorial traits in developed food products as well. It is often believed that people with increased intake of such functional diets are at lower risk to acquire chronic illnesses thus reducing the risk of mortality (Jenkins et al., 2008; Saeed et al., 2014). It is therefore important for nutritionists and health professionals to take interests in plants and their products for their multifarious functionalities. In this context, cereal grains, pseudo-cereals and psyllium husk are classified as plant based foods with considerable nutritive and non-nutritive constituents (Beaugrand et al., 2004; Butt et al., 2008). Amongst plant sources, cereals are ranked as the leading protein source, although plant proteins are often incomplete proteins (Day et al., 2013), due to lack of essential amino acids (Galili and Amir, 2013). Over the years, pseudo-cereals i.e. quinoa, buckwheat and amaranth have attracted a lot of attention owing to their momentous nutritious profile (Margitanova et al., 2012). Furthermore, they possess substantial amounts of bioactive components and micronutrients such as vitamins and minerals (Berghofer and Schoenlechner, 2002; Wijngaard and Arendt, 2006; Alvarez-Jubete et al., 2010a). Cereals and pseudo-cereals are the principal carbohydrate source for the world’s human population (Brennan et al., 2012). Pseudo-cereals i.e. quinoa, amaranth and buckwheat are different from the gramineae family, being part of the dicotyledonous family. These plants produce seeds which are used similar as cereal grains in chemical composition, and processing applications (Iglesias-Puig et al., 2015).

Quinoa is dicotyledonous seed producing annual branched or unbranched plant of 1-2m height. The quinoa seed color may be green, yellow, red or purple depending on variety. Quinoa is dicotyledonous herbaceous, facultative halophyte belonging to family Amaranthaceae which include wild and domesticated plants population (Watanabe et al., 2003; Bertero et al., 2004; Pulvento et al., 2010; Ruiz et al., 2013)

Quinoa is a multipurpose agricultural seed producing crop. Its seed and flours are utilized as foodstuff in bakery products reasoned to their high nutritional value (Repo-Carrasco-Valencia et al., 2010b). Moreover, their proteins have high nutritional value and better amino acid score due to the presence of higher level of lysine as compared to other cereals (Watanabe et al., 2003). Therefore, quinoa flour can potentially be used as a substitute for
wheat flour in the production of baked products like pasta, snacks, bread and crackers (Chavez-Jauregui et al., 2000; Caperuto et al., 2001; Morita et al., 2001; Weeks, 2010). Comparatively it has higher nutritive components like minerals, protein and vitamins. Due to their health-promoting effects, these crops may be introduced into variety of food products (Christa and Soral-Smieta, 2008; Schoenlechner et al., 2010b). The consumption of quinoa as a novel ingredient in the production of enriched bakery products that have higher nutritional value (Taylor and Parker, 2002).

Quinoa seeds are characterized largely on protein quality rather than its quantity, as numerous essential amino acids *i.e.* leucine, isoleucine, methionine, lysine, valine, tryptophan, threonine and phenylalanine are present in it (Koziol, 1992; Vega-Galvez et al., 2010). Amount of protein in quinoa seeds is higher than many of other cereals (12-20 %) and almost all of the amino acids quinoa proteins have been identified (Miranda et al., 2012a). Moreover, amino acids content in quinoa are higher both in quality and quantity than other cereals crops (Wright et al., 2002a; Vega-Galvez et al., 2010), particularly the content of lysine is interesting as it is a necessary amino acid for the growth and development (Escuredo et al., 2014).

Diet based therapies and ever escalating incidence of nutritional ailments have provoked for the ingress of diets as functional foods and nutraceuticals. In this milieu, quinoa emerges as a prospective choice that fulfills almost all nutritional requirements while ensuring health-promoting properties (Vega-Galvez et al., 2010; Abugoch et al., 2011). Quinoa seeds also contain water & fat soluble vitamins, antioxidants, flavonoids and phenolic acids (Repo-Carrasco-Valencia et al., 2010a; Miranda et al., 2012a). It is generally assumed that populations with increased intake of flavonoids have a reduced tendency to acquire cancer and other metabolic syndromes. Further apart, vibrant antioxidant profile of quinoa seeds with fairly good presence of quercetin and kaempferol glycosides is instrumental in restricting degenerative diseases and other physiological syndromes (Hirose et al., 2010).

Quinoa has the capability to tolerate harsh climatic conditions like drought, frost, soil salinity and due to this reason it has been nominated by FAO as the potential crop that intended to offer food security (Jacobsen et al., 2003). The quinoa has been classified on the basis of nutritional composition and its genetic makeup due to strong variability in genetic, as well owing to the impact of environmental situations (Repo-Carrasco et al., 2003; Escuredo et al., 2014).

The flour of quinoa contains about 11.2% moisture, 58.3% carbohydrate, 9.5% crude fiber,
13.5% crude protein, 6.3% ether extract and 1.2% total ash. The quinoa has low content of glucose (19%) and fructose (19.6%) and high quantity of d-xylose (120%) and maltose (101.0%) (Nascimento et al., 2014). Quinoa has 7% oil content on dry basis lower than soy (20.9%) and higher than corn (4.9%) (Przybylski et al., 1994; Ryan et al., 2007). It comprises of total polyunsaturated fatty acid (58.3%) majorly linoleic acid (about 90%) total monounsaturated 25–28.7%, mainly oleic acid; while total saturated 19–12.3%, mainly palmitic acid (Ryan et al., 2007). The fatty acid profile of quinoa seed is similar to corn and soybean oil (Youdim et al., 2000). According to Perini et al., (2010), linoleic and α-linolenic fatty acids are essential because these are not produced by human through de novo synthesis and must be provided by an adequate diet. The ingestion of unsaturated (oleic acid) instead of saturated fatty acids helps to reduce the low density lipoprotein levels in blood and, therefore, cardiovascular diseases will occur with a lesser probability (Elmadfa and Kornsteiner, 2009; Palombini et al., 2013).

Apart from other dietary cereals, quinoa differs in the manner of food storage for development of embryo because it stored in the perisperm of seed rather than in endosperm. Furthermore, dicotyledonous embryo being a part of bran fraction, is high in protein and lipid. Additionally, embryo abounds in ash, fiber and saponins contents. Quinoa starch is known to be low amylose with improved cooking quality attributes (Lindeboom et al., 2005a). Quality and quantity of quinoa protein with reference to its amino acids are similar to milk protein (Casein) and highly comparable to cereal crops (Berti et al., 2004). Quinoa recently has been utilized as a novel functional food due to its incredible characteristics; it is an auspicious substitute cultivar in the world (James and Lilian, 2009).

Nutritionally, quinoa seeds are known to be rich in their vitamin and mineral profile with substantial amount of these essential nutrients present. Generally, composition of quinoa vitamin is somewhat similar to that of cereal crops (Taylor and Parker, 2002) with considerable thiamin (0.29 - 0.36%), riboflavin (0.30 - 0.32%), total folate (0.18%) and vitamin B₆ (0.487%). Moreover, quinoa seeds are fairly good source of ascorbic acid with levels ranging from 4.0 to 16.4mg/100 g (Valcarcel-Yamani and Lannes, 2012). Besides, quinoa seeds are good source of vitamin E with almost two time higher γ-tocopherols (5.3 mg/100g) and α-tocopherols (2.6 mg/100 g) as compared to other crops (Ruales and Nair, 1993). Additionally, vibrant nutritional profile of quinoa also ensures provision of total folate and vitamin B₆ levels to children and adults. Thiamin content in quinoa is lower than those in oat or barley, but higher in niacin, vitamin B₆, riboflavin and total folate (Ranhotra
et al., 1993; Konishi et al., 2004). The phytochemicals includes phytosterol, squalene, flavonoids, saponins and phenolic acids are present in significant amount in quinoa (Gorinstein et al., 2008). Bioactive components i.e. phytosterol, squalene, flavonoids, saponins and phenolic acids are also present in good concentrations (Jahaniaval et al., 2000). As a food constituent, squalene has the ability to restrict cholesterol synthesis in liver by interfering with its absorption (Jacobsen et al., 2003; Sindhuja et al., 2005; Stikic et al., 2012).

Quinoa flour has various functional properties like water binding capacity, solubility, gelation, foaming and emulsifying that allow it for diversified uses (Bilalis et al., 2012). In addition it contains higher quantity of oil than other cereal crops with prominent vitamin E content and higher quantity. Quinoa starch has physicochemical characteristics such as freeze stability, viscosity which give it functional properties with novel uses (James and Lilian, 2009). The health promoting and maintaining colon health factors are associated with quinoa which play numerous important role in preventing gallstones and this is due to the high availability of insoluble dietary fiber. The vitamin profile of quinoa is very rich including vitamin B and folate that enhance the performance of lover and improve the ability of toxin removal from body (Chavez-Jauregui et al., 2000; Caperuto et al., 2001; Morita et al., 2001; Asao and Watanabe, 2010).

Besides, pseudo-cereal proves to be a suitable substrate for dough aeration using yeast, since considerably more glucose and a higher activity of α-glucosidase are found in comparison to rice and corn flour. Consequently, quinoa white flour are used to replace 40-100% of the rice and corn flour in a gluten-free control recipe. As a result, quinoa white flour enhanced the specific volume by 33%, which are related to the absence of bran components and the increased α-glucosidase activity (Elgeti et al., 2014).

The use of pseudo-cereals and ancient grains for bread making applications is getting particular attention since these involve nutrient dense grains with proven health-promoting attributes. Dough viscometric and viscoelastic features showed a positive correlation due to the dilution of wheat/rye flour blend up to 20% with cumulative addition of quinoa, buckwheat, amaranth and teff flours (5% single flour). Furthermore, techno-functional and nutritious properties of mixed bread matrices are also known to enhanced with induced concomitant dynamics in lipid binding over mixing and baking steps (Collar and Angioloni, 2014).

The in-vitro digestibility of quinoa protein varies between 76.3-80.5% on the basis of
varieties (Repo-Carrasco-Valencia and Serna, 2011). Its protein contents are incredible and their composition regarding essential amino acids is tremendous. Its balanced configuration makes the quality of quinoa protein similar to that of casein protein (Kozioł, 1992; Ranhotra et al., 1993; Rojas, 2003). Regardless of the tremendous nutritional profile; these also contains anti-nutritious components in the pericarp like saponin, in a different amount depending generally on their variety (Ward, 2000) as well as on the environmental conditions specially stress conditions of the plant (Mastbroek et al., 2002; Pulvento et al., 2010; Szakiel et al., 2010)

Quinoa is less well-known plant in the subcontinent; however there has been increasing attention in quinoa crop due to perception of its superior nutritive worth in comparison to other grains crops (Gonzalez et al., 2012). Pakistan is a region together with practically half of the people immediately influenced by agricultural career. To some cautious evaluation, a lot more than 57% from the kid populace is actually malnourished; seventy seven million individuals are meals unconfident as well as nation rated 11th within the listing of the majority of meals unconfident nations on the planet. Conventional feed plants such as grain, whole wheat as well as maize are in risk as a result of quantity of biotic as well as abiotic elements such as insect pests, water unavailability, dirt salinity, surges as well as bad soil nourishment. With this viewpoint, wholesome feed plants such as quinoa that has higher threshold in order to salinity, drought as well as bad soil nourishment tend to be among the remedies in order to save humanity through food cravings as well as malnutrition (Ahmad and Malik, 2002). In spite of its clear potential to nourish developing countries, quinoa is under supported and under researched, considered as ignored crop. Regarding cultivation, it is cultivated annually only on the area of 101,500 ha worldwide although its annual production has increased up to 70 % when compared with last 12 years, to around 80,200 tons (Zurita-Silva et al., 2014)

The current project is an effort to probe the nutritional worth of quinoa and its utilization in food products. Due to higher nutritional value of Quinoa, it has great potential for improving food for humans. Chemical composition explained the potential of quinoa as most valuable ingredients in the bread production to enhanced nutritional characteristics. The results described the possibility of nutritionally valuable product with acceptable sensory acceptance. This may contribute to the origin of the commercial value of the Pakistani quinoa in national and international markets.

The total area of Pakistan is 79.6 million hectare from which 22 million hectare is available
for agriculture. Among the 22 million hectare only 18 million hectare is under irrigation and 4 million hectare is under rain fed. In the northern mountains covering 100,000 Km², where conventional Agriculture is difficult, the problems are loss of soil fertility and lack of suitable crop which can improve the agricultural economy (Ahmad and Malik, 2002). In this context, researcher are now mainly focusing on those crops grown in poor soil and under rain fed area. Among those crops, quinoa is most prominent crop that can be grown in poor soil condition. So keeping in view the above facts and figures the current study has been designed with following objectives;

- To characterize quinoa flour for its chemical and nutritional profile
- To extract protein isolates from quinoa and exploit its functional properties and elucidating the effects of quinoa flour on rheological, textural and sensorial characteristics of products
- In-vitro and in-vivo evaluation of quinoa protein
CHAPTER 2 REVIEW OF LITERATURE

Cultivation of nutritious crop with minimum input are becoming necessity to fulfill the needs of increasing world population. The food demand has been increased dramatically over the last decades due to the massive increase in population as well as increase in the people’s purchasing power (Aggarwal, 2008). However, a large part of the world’s population, specifically in the developing countries, still has diminutive provision to mineral rich diet and protein, as wheat and rice are the leading dietary staples. Each person must eat sufficient amount of good quality and safe food throughout the year in order to meet all nutritional requirements for maintenance of body, work and recreation, for growth and development. Probably 7000 plant species have been used as crop plants, nowadays only 150 species of different plants are cultivated among these just 12 species provide roughly 75% of the world’s food and 4 species produce above 50% of the world’s food. Common facts range from thirty plant species providing 95% of human nutrition and seven plant species providing 75% of human nutrition (Bhargava and Srivastava, 2013). These frequently utilized crops are ultimately cultivated intensively and need farm mechanization that increased inputs in different forms like high-yielding varieties, labor, chemical fertilizers and pesticides (Bhargava et al., 2008).

Meanwhile the stress on some major cultivated crops has constricted many species on which global food security depends. The consequences of crop letdowns from unexpected stresses, diseases and pests can be disastrous (Prescott-Allen and Prescott-Allen, 1990). The past three decades have seen extensive array of research interests on different underutilized crops and many significant programs have been intimated different countries to encourage the underutilized species, as substitute crops or as sources of innovative products (Mayes et al., 2012).

These underutilized species look like to have significant potential for use, yet their potential is just exploited, if not totally ignored, in agricultural production (Hammer et al., 2013). Underutilized species are normally known as ‘new crops’, it is not because they are ‘new’ but because due to that these have been taken up by agricultural scientists and investors for new marketing (Bhargava and Srivastava, 2013). Many uninhabited and underutilized crops have potential for more widespread uses and could contribution toward the food security, agricultural divergence and income generation (Vietmeyer, 1986). Ignored and underutilized species of different crops represent significant revenue sources for local
thrifts and are portion of the rich national and traditional culture of civilizations around the world (Danso et al., 1990).

Furthermore, these underutilized crops are imperative source of resilient genes for abiotic and biotic stress breeding conditions that can also be used for the genomic development of different cash crops. When compared with main cultivated crops, these need somewhat less inputs and, so can give to sustainable agricultural invention. These neglected or underutilized crops possessed pronounced prospective to relieve hunger, through cumulative food production in difficult situations where main crops are harshly limited, in the manner of nutritional development in diets specially concentrated on staples food and through providing the poor with purchasing power, helping them purchase the food that is available (Mayes et al., 2012).

Among various underutilized crops, members of the genus Chenopodium family *Amaranthaceae* are most promising since these have the capability to boom and flourish under stressful situations (Jacobsen et al., 2003; Bhargava et al., 2006) as well as on soils with least agricultural inputs. Chenopodium has an important role to play both as a cash crop and as a nutritious food crop (Bhargava et al., 2008).

Among new crop all over the world, *Chenopodium quinoa* frequently known as ‘quinoa’, is one of the record neglected crop, given its wonderful seed protein alignment and having yield potential. It is predominantly a grain crop, harvested and utilized in a style as similar to that for cereal grains, while its leaves can also use as a salad (Hariadi et al., 2011). In this context, quinoa is a pseudo cereal with a dicotyledonous seed in contrast to other cereals that are monocotyledons (Valencia-Chamorro, 2003). Over the last two decades, quinoa has levitated from derelict crop to a profitable and productive crop of Andean nations of Peru and Bolivia (Jellen et al., 2011). The stages in development of quinoa from a neglected crop to super food has gathered immense recognition by the scientists and researchers in attaining it as a nutritional beneficial crop with novel biotic and abiotic stress-tolerance.

Quinoa (*Chenopodium quinoa* Willd.) is known as pseudo-cereal inherent to South America. The quinoa plant can be unbranched or branched contingent on variety. It is deliberated as multiuse agricultural crop. The seeds of quinoa may be consumed as human foodstuff, in the form of flour, baked products and as well as for animal feedstock due to its extraordinary nutritional worth (Repo-Carrasco-Valencia et al., 2010b). Furthermore, their proteins have extraordinary nutritional worth because the tremendous levels of lysine
compared to cereals such as wheat and rice and have extraordinary amino acid score (Watanabe et al., 2003). For that reason, quinoa flour used as replacements for wheat flour in the production of nutritious products like pasta, bread and snacks (Chavez-Jauregui et al., 2000; Caperuto et al., 2001; Morita et al., 2001). Moreover, the quinoa plants are more resistant to grow under drought condition, salinity, frost and can even grow on low fertile soils (Jacobsen et al., 2003).

Quinoa is cultivated in a wide-ranging environmental conditions in the South America at 20°N latitudes in Colombia to 40°S in Chile (Risi and Galwey, 1991). It has been familiarized in North America, Europe, Africa and Asia (Bhargava et al., 2006). European and American examinations of quinoa have produced some good outcomes with a potential to serve as nutritious food as well as fodder choice (Jacobsen et al., 2003; Bhargava et al., 2006).

The nutritive distinction of quinoa crop has been recognized since ancient times in Inca Empire. The significance that quinoa crop could play in nutrition has been highlighted not only in developed world but also in the developing countries. Quinoa seeds have advanced nutritive value than most cereal grains and comprises the high-quality protein and large amounts of carbohydrates, minerals vitamins, and fat (Ruales and Nair, 1994; Wright et al., 2002a; Vega-Galvez et al., 2010).

Perisperm, endosperm and embryo are three parts known to serve as storehouse in the seed of quinoa (Prego et al., 1998) shown in Fig 1. Starch part of seed is stored in perisperm on the other hand protein and lipids stored in embryo and endosperm. The FAO has observed that quinoa seeds have superior proteins, and higher levels of calcium, iron, phosphorus, vitamins and fiber (Dini et al., 2005).

Figure 2.1 Chenopodium quinoa Grain Structure (Prego et al., 1998)

Median longitudinal segment of the seed. Pericarp (PE) which covers the quinoa seed. Embryo part comprises of hypocotyl radicle alliance (H) and also have two cotyledons (C). Endosperm (EN) is existing in the micropylar section.

Quinoa crop was initially classified on the basis of color of plant and their fruits/seed. Afterwards, its classification was done on the basis of plant morphology. Regardless of
extensive deviation perceived. Quinoa crop is thought to be distinct single species. On the basis of practical explanations quinoa has been categorized as a race like maize. Quinoa collected in Bolivia, Ecuador and Peru, has been classified into 17 races, on the other hand, more races may be present. Two sorts of inflorescence have been reported, “Amaranthiformes” and “Glomerulates” (Valencia-Chamorro, 2003; Jancurova et al., 2009b).

2.1 Chemical composition of quinoa seeds

2.1.1 Carbohydrates/Starches

Carbohydrates perform a role as nutritional function in living organisms and have number of physiological health effects. Carbohydrates can be classified on the basis of their degree of polymerization. In quinoa grains starch is the important carbohydrate, contributes approximately 58.1-64.2% of the seed on the basis of dry matter (Repo-Carrasco et al., 2003). It delivers the prime energy source to human; besides it is categorized as obtainable carbohydrate (Tharanathan and Mahadevamma, 2003). In quinoa seeds, starch is the most significant carbohydrate covering almost 32-75% of the seed (Chauhan et al., 1992; Ahamed et al., 1998; Ando et al., 2002; Wright et al., 2002a; Lindeboom et al., 2005a).

Quinoa starch composes of two polysaccharides named as amylose and amylopectin. It has been reported that the content of amylose in quinoa starch is comparatively less on the other hand amylopectin portion of quinoa starch differs between 3% and 20% (Abogoch James, 2009). Starch is made of just of glucose deposits, that are connected collectively through α-1, 4 bonds as well as branched by way of α-1, 6 provides to create amylose and amylopectin respectively (Jane et al., 1999). Amylose is predominantly linear with very a small number of branches, whilst amylopectin is extremely branched. The major element of most starches is amylopectin, and its fine configuration plays a vital role for starch characterization. Generally, the branches within amylopectin do not happen arbitrarily; somewhat, they are organized in grouping therefore permitting the development of dual helices. These helices may load up collectively within structured crystalline lamellae that are detached through amorphous areas which are mainly made up of amylose. This arrangement of both amylose and amylopectin is in fact the foundation of semi-crystalline framework of starch granules (Abogoch James, 2009).

It has been reported that quinoa starch granules have a polygonal configuration with a 2 μm diameter; quite less than starch of other common cereal grains (Vega-Galvez et al., 2010). The granules may be existing in the perisperm as joined substance or as single items.
structures (Lorenz, 1990). The starch is in stationary condition inside a matrix accompanying with proteins that declines the hydrolysis occurred by enzymes of the starch, thus it effect to dropping its digestibility in addition to extractability (Atwell et al., 1982; Praznik et al., 1999).

The proportion of amylose in order to amylopectin is one of the crucial elements finding industrially essential qualities. In several plants, starch contains 20-30% amylose alongside 70-80% amylopectin (Praznik et al., 1999). Starch digestibility depends on its intrinsic structure, crystallinity, physical encapsulation, degree of gelatinization, retrogradation and proportion of damaged granules (Ruales and Nair, 1994). The starch digestibility might also be affected by the development of complexes between lipid and amylose, protein and starch interactions, the occurrence of some anti-nutritional factors such as amylase inhibitors, processing techniques, modification of its structure and functional groups (Eyaru et al., 2009; Wong et al., 2009; Putseys et al., 2010; Barrett and Udani, 2011). The starch of quinoa is exceptionally branched, with both least and greatest level of polymerization (Praznik et al., 1999). Chain length depends on the plant source of the starch and is possible to be of the order of 500–6000 glucose units. Substantial variations has also been reported in the amylose content of quinoa seed, which has been establish to be around 3–20% (Lorenz, 1990; Praznik et al., 1999; Repo-Carrasco et al., 2003; Watanabe et al., 2003; Tang et al., 2005). Amylose content of the starch affects physico-chemical and functional properties (Li et al., 1994; Wootton et al., 1998; Baldwin, 2001; Bao et al., 2001; Grant et al., 2001; Svegmark et al., 2002; Lindeboom et al., 2005a).

Various data have been reported on the quinoa starch properties (Atwell et al., 1982; Lorenz, 1990; Tang et al., 2005). It is available as little granules about size ranging from 1–1.5μm in diameter (Lorenz, 1990; Chauhan et al., 1992; Qian and Kuhn, 1999; Wright et al., 2002a). Starch granule size considerably affect physicochemical traits of starch and is interlinked to the biological source of starch isolation and extraction. The particle size of quinoa is less than that reported for maize (1.0-7.7μm) wheat (0.7-39.2μm), barley (1.0-39.2μm) and rice (0.5-3.9μm) (Ando et al., 2002). The tremendously granule size of quinoa starch can be subjugated by utilizing it as a decomposable filler in polymer packing (Atwell et al., 1982). Starch of quinoa has a normal molar mass of 11.3×106g/mol, which is equivalent to that of other pseudo-grain like amaranth (11.8×106g/mol) starch, and greater than cereal i.e. wheat starch (5.5×106g/mol), however it is lower than that of rice starch (0.52-1.96×108g/mol) and waxy maize starch (17.4×106g/mol) (Lindeboom et al., 2005a;
Park et al., 2007). The quinoa starch shape has been determined by using scanning electron microscopy and has been illuminated as polygonal (Lorenz, 1990; Ruales and Nair, 1994; Qian and Kuhn, 1999; Lindeboom et al., 2005a), which is like to starch of rice and amaranth (Qian and Kuhn, 1999; Kong et al., 2009). Likewise the starch has polygonal granules and the particles can be exist singly and aggregates in spherical forms are packed in the quinoa perisperm (Atwell et al., 1983; Ruales and Nair, 1994; Ando et al., 2002).

Quinoa starch has been shown to reveal the distinctive A-type X-ray diffraction configuration (reflections at 15.3°, 17.0°, 18.0°, 20.0° and 23.4° 2θ angles) (Watanabe et al., 2007) which are same as characteristic of different cereal starches (Watanabe et al., 2007; Lopez-Rubio et al., 2008). The level of relative crystallinity of starch differs somewhere around 35% to 43% (Tang et al., 2002; Watanabe et al., 2007), which is lesser than that of other pseudo-cereal specially amaranth starch, greater than that of normal barley starch and it is quite similar to of the waxy barley starch. Meanwhile amylose is recognized as to interrupt the structure order within the amylopectin crystallites, the crystallinity of starch is allied with amylose content (Qian and Kuhn, 1999; Tang et al., 2002).

Starch gelatinization involves the disruption in the molecular structural order in the starch granule on heating beyond its temperature of gelatinization in the presence of surplus water. Despite heat, higher level of an alkalinity might also induce gelatinization of starch (Lai et al., 2002; Roberts and Cameron, 2002). Starch have gelatinization abilities that tend to be linked with a number of elements such as the size, type of crystalline arrangement, percentage, as well as the starch granule ultra-structure. Starch of quinoa gelatinizes in a fairly reduced heat that is comparable to the temperature of gelatinization of potato as well as starch of wheat, but lesser than starch of corn (Lorenz, 1990). The quinoa starches showed comparatively lower gelatinization temperatures but higher than rice starch, when matched with amaranth and waxy barley starches (Qian and Kuhn, 1999; You and Izydorczyk, 2007). Moreover, quinoa starch pasting behavior is significantly different from wheat starch’s properties. At equivalent starch concentrations, quinoa starch shows a higher viscosity (Atwell et al., 1983).

Pasting temperature of quinoa (66.8°C) was reported by Qian and Kuhn (1999), which is relatively similar to the result reported by Wright et al. (2002a) (63.5–65.3°C) and Lindeboom et al. (2005a) (63-64°C). Stability of quinoa starch is also outstanding under the processes of retrogradation and freezing (Ahamed et al., 1998). The term retrogradation
alludes to changes which happen amid cooling and stockpiling of gelatinized starch glues, changes that regularly diminish the nature of starch-based sustenances (Lindeboom et al., 2005a). Retrogradation of quinoa starch arrays from 19.6 to 40.8% of the gelatinization enthalpy. Content of amyllose showed as noticeable aspects in the process of starch retrogradation, with a more elevated amyllose content causing in more starch molecules association and a greater degree of retrogradation (Chang and Liu, 1991; Fan and Marks, 1998; Kaur et al., 2002). The fact that quinoa starch is resistant to retrogradation recommends that it can be useful in frozen food products, cream soups, sauces pie fillings and in emulsion types of food products such as salad dressings (Ahamed et al., 1996).

Gelatinization enthalpy associated with starch of quinoa is 7.3-10.5 J/g, when it is compared with starches of other crops like potato starch (18.8J/g), regard to corn starch (17.2-20.5J/g), wheat starch (12.1 J/g), along with regard to the starch of rice (14.2-16.3J/g) (Zobel, 1984). Even though starch of quinoa gelatinizes at the same temperatures, its pasting character is substantially not the same as that of starch of wheat. From equivalent starch levels, starch of quinoa presented a greater viscosity whenever calculated by using amylograph (Atwell et al., 1982). Starch of quinoa discovered to hold a greater water-holding capability and greater inflammation energy as compared to starch of barley or wheat. Additionally, it is tremendously stable to freeze-thaw as well as shows small retrogradation, because of its reduced amyllose content (Lorenz, 1990). Praznik et al. (1999) studied reduced freeze-thaw constancy for gels of quinoa starch than other pseudo-cereal like amaranth, buckwheat, as well as starch of wheat gels. Quinoa starch revealed to be a more viscous for fillings when compared with barley, wheat and potato in addition to the starch of amaranth. Ruales and Nair (1993) evaluated the nature as well as degree of fluctuating of starch of quinoa brought on by various procedures like cooking, autoclaving, extrusion as well as drum drying by computing its physicochemical qualities. All methods changed the physicochemical qualities of quinoa starch at different levels.

2.1.2 Fiber

Quinoa is outstanding source of both soluble and insoluble dietary fiber which are consisting of about 6% of the total grain (Jacobsen et al., 2003). According to the research carried out by (Repo-Carrasco et al., 2003) quinoa have more insoluble fiber about 80% of total fiber was insoluble. Ruales and Nair (1994) discussed that an overall total fiber content associated with quinoa was 13.4% comprising 2.4% soluble fiber along with 11.0% insoluble fiber. The content of soluble and insoluble fiber in quinoa was higher than that of
wheat (just likes rye) but insoluble fiber content at somewhat in lesser amount. This may be due to various types, variations in processing of seed. The fiber content of quinoa did not affect when the outer covering of seed detached by washing and scrubbing with the aim of saponins removal. Quinoa is commonly measured to have higher in fiber contents (Ranhotra et al., 1993; Ruales and Nair, 1994), although crude fiber percentage comparatively low about 1.1% has been documented (Becker and Hanners, 1990)

2.1.3 Protein

The nutritious excellence of product relies upon the presence of quality and the quantity of the protein (Repo-Carrasco et al., 2003). The mean content of protein described for grain of quinoa is range from 12-23% (Kozioł, 1992; Ruales and Nair, 1994; Ando et al., 2002; Karyotis et al., 2003; Abugoch James, 2009; Gonzalez et al., 2012), which is higher than that of other cereal crops specially rice, maize or barley and is similar to protein of wheat (Abugoch James, 2009).

Wright et al. (2002a) documented 15.7% and 14.8% of protein for bitter and sweet quinoa respectively. When these are equated to other cereal grains, protein contents in quinoa is comparatively higher than that of maize (13.4%), rice (7.5%) or barley (11%), and is analogous to that of wheat (15.4%) protein (Abugoch James, 2009). The concentration of protein content in quinoa seed is higher in plants which are grown in controlled environmental conditions as compared with the plants grown in field studies. This is possibly due to increased nutrient availability and lessened stress in controlled environmental condition. It is often assumed that nutritive worth of food is largely characterized by quality of its protein that often interrelates with anti-nutritional factors (Comai et al., 2007). The essential amino acids are not synthesized by animal body and they need to be provided in the diet. In their absence, other amino acids will degrade themselves resulting in poor growth and loss of nitrogen in the diet (Vega-Galvez et al., 2010).

Importance of the quinoa proteins is mainly due to its quality. Quinoa proteins belong to globulin and albumin, which possessed balanced essential amino acids similar to the configuration of amino acids in milk protein (Ranhotra et al., 1993). Kozioł (1992) reported that globulins and albumin were the major protein fractions in quinoa protein, on the other hand the proportion of prolamines and glutelin was comparatively low. Major protein of quinoa were isolated and categorized which was named as chenopodina, chenopodina is a 11S type globulin protein , which separated into two subcategories, A and B possessing
dissimilar molecular weights around 32-39 and 22-23 KDa respectively, which are greater than that of milk casein protein. Molecular studies of quinoa protein i.e. albumin and globulin configurations have revealed that both type of proteins become stable by disulphide bonds (Repo-Carrasco et al., 2003) (Brinegar et al., 1996).

Mahoney et al. (1975) documented the value of protein efficiency ratio (PER) quinoa originated from Bolivia. It was determined that the protein quality of cooked quinoa was similar that of casein with high content of methionine and lysine. It have been reported that the protein efficiency ratio of the heated quinoa was 30% higher than that of raw quinoa. For the nutritional quality of proteins, the protein efficiency ratio (PER) or net protein utilization (NPU) are generally used as indicators. The PER in food is calculated by dividing the gain in the weight of assessment subject by the intake of that specific protein for the duration of the test period. The PER has been developed as a standard for assessing the quality of protein present in the food, especially in the advanced countries.

Gross et al. (1989) described a high apparent digestibility and a high PER of washed quinoa seeds where they found that the PER is more or less equivalent to that of casein protein. The quality of quinoa protein was assessed in terms of rat response and amino acid configuration of protein. Results demonstrated that cooking of quinoa improved the efficiency of nitrogen for development around 40%, protein efficiency ratio by 29% and the gain of weight up by 100%, Mingling 20% quinoa with 80% wheat flour enhanced the efficiency of nitrogen for development by 43%, protein efficiency ratio by 72% and gain of weight up to 11% above wheat flour alone. Heating process of bread may decrease efficiency of nitrogen for development by 9%, protein efficiency ratio by 19% and weight gain up by 14%. The enhanced efficiency of nitrogen for development, protein efficiency ratio and weight increase of the cooked quinoa on the uncooked quinoa did not exposed variation in composition of amino acids. There were some changes in the composition of body and weight gain of organ between different diets (Mahoney et al., 1975).

Quinoa protein products showed solubility of 47.0-93.0% that depending on technique of protein concentration and the material extracted (Lindeboom et al., 2005a). The solubility of the quinoa protein based products were reportedly greater than soybean protein based products. Besides, these were quite close egg white protein. The solubility of the protein concentrate from defatted and saponin removed bran was lesser as equated with other protein products. On precipitation, protein aggregates were prepared which were difficult to solubilize i.e. the solubility of protein decreased on extraction of saponin. For that reason,
the solubility of obtained protein from bran without saponin removal, was high (93.0%). Saponins and other extracted substances in ethanol 60%, like antioxidants, might be effected by the denaturation, configuration, and resolubilization sedimentation of protein (Aluko and Monu, 2003; Lindeboom et al., 2005a). Lindeboom et al. (2005a) repotted that quinoa protein foaming capacity is lesser than soybean protein but better than egg white. The results were in contrast to those found earlier by Aluko and Monu (2003), who determined that protein of quinoa possessed significantly low foaming capacity, the low foaming capacity might be due to the quinoa protein globular nature, globular nature of protein decline its ability to made interfacial covers around the bubbles air. The foam stabilities of quinoa protein foodstuffs have been described to be lower than that of egg white protein, comparable and comparatively greater than protein of soybean (Lindeboom et al., 2005a).

The quinoa seed proteins possess a balanced ratio of essential amino-acid with higher quantity of histidine, methionine and lysine (Koziol, 1992). The total amino acid configuration (free amino acids and protein-bound) of quinoa seeds showed deviation during development of seed. The comparative quantities of arginine, glycine and glutamic acid improved as the quinoa grain developed. On the other hand, the quantities of proline, aspartic acid, valine, lysine, threonine, and serine decreased. Major increase in glutamic acid have been observed which was 13.9% on the fourth day to 15.1% and 21.7% at the maturity, which were most copious during the development of seed (Prakash and Pal, 1998). Glycine ranged from 8.0 to 8.7% on the 12th day, 9.0% on the 16th day, and 9.9% at maturity. Serine (5.7-4.8%), lysine (7.3-5.8%) and threonine (4.6-3.4%) showed decrease from the 4th day to the time of maturity. The differences in the relative quantities of different amino acids showed that there might be an indirect or direct association among the utilization and metabolism or synthesis of amino acids during development of seeds. Additionally, seed needs to be collected at a precise level of maturity to achieve protein part with greater quantities of specific or essential amino acids (Raina and Datta, 1992).

Moreover, the essential amino acid stability is outstanding due to presence of wide-range of amino acids, with higher contents of methionine (0.4-1%) and lysine (5.1-6.4%) (Bhargava et al., 2006; Bhargava et al., 2007; Abugoch James, 2009). In quinoa seeds the quantity of essential amino acids is comparatively greater than present in other cereal crops (Ruales and Nair, 1992; Wright et al., 2002a). Quinoa proteins possess higher histidine content than proteins of soy and wheat, despite of the cystine and methionine content of
Quinoa is satisfactory for children and adults requirement, it is alike to that of soya protein and higher than that of amounts of protein in wheat. In quinoa, leucine and lysine are the limited amino acids, while all essential amino acids are abundant according to the suggested requirements (James and Lilian, 2009). Therefore, the quinoa seeds protein quality is superior to most cereal grains. Quinoa proteins may be remarkable promising nourishment constituents, capable for fulfilling legumes or cereal proteins, and these can be utilized as a potential source for the preparation of protein concentrates from quinoa seeds, which potentially will be utilized as raw materials for development of new products in the food industry. The energy value and high protein quality of the grain can be consumed in the poultry industry. The virtuous amino acid composition could be a good source of proteins for nourishing of children and infants. It is motivating to note that the protein of quinoa have high amount of sulfur-containing amino acids when compared with other seed producing plants (Vega-Galvez et al., 2010).

Nevertheless, the quinoa seed digestibility is the limiting aspect in energy and protein utilization (Lopez de Romana et al., 1981), which can be significantly changed into better-quality by milling. (Lorenz and Coulter, 1991) prepared grits by mixing corn with different level of quinoa and observed that by the adding quinoa in extruded products showed higher in protein content than corn grit, on the other hand had lower in vitro digestibility. Studies regarding enzymatic hydrolysis have showed that peptides with short-chain are comparatively more active in quinoa grains rather than peptides with long-chain. Peptides with low molecular weight generally have greater health potential as antihypertensive agents or as complexes that reduce the quantity of free radicals as compared to high molecular weight peptides (Aluko and Monu, 2003).

Quinoa protein was compared with other protein of cereals crops, it was observed that it is specifically full of amino acids, lysine, histidine and isoleucine along with methionine which is restricting amino acid in other cereals. Quinoa proteins have superior amount of histidine as compared to soya, barley or even whole wheat crop. It's higher methionine accompanied by cysteine support to make quinoa great substitutes to legumes, which are restricting within sulfur containing amino acids (Fairbanks et al., 1990). Quinoa proteins also provide adequate quantities of aromatic amino acids in consort with phenylalanine, threonine isoleucine, histidine, tyrosine as well as valine (Aluko and Monu, 2003).

Prolamins content of quinoa proteins are lesser 0.5 to 7.0% that indicates quinoa is free from gluten protein, therefore it is non-allergenic (Galwey, 1992). It is suitable and
attractive with respect to use within meals prepared to decline allergic responses within
delicate person’s for instance celiac ailment in addition to within baby formulae (Morita et al., 2001). Quinoa proteins comprise two key proteins portions, the first one is an 11S-type
globulin, named as chenopodin. This shear about 37% of the whole proteins and owns 22-
23kDa along with 32-39kDa weight of polypeptide. This type of protein when equated with
amino acid configuration of whole protein had minimized sulfur holding amino acids like
methionine in addition to cysteine (Brinegar et al., 1996).

An additional key proteins, which makes up about 35% from the whole proteins contained
by quinoa possessing with molecular weight 9kDa, is actually a 2S-type protein. Such
protein might be a brilliant source of histidine, cysteine, and also arginine, however quite
weak source of methionine. Both core type of quinoa protein differ specifically in their
solubility at pH 5, where the mainstream of 2S proteins stays to be soluble while 11S is
drag out (Brinegar and Goundan, 1993). The common portion of quinoa protein comprise
of albumin and globulin, that might have well-proportioned configuration of vital amino
acids just comparable with casein protein. The leaves of quinoa as well make available of
a higher content of high quality protein, moreover they are full of vitamins and minerals,
mainly calcium, iron in addition to phosphorus (Repo-Carrasco-Valencia et al., 2010b).

Quinoa have relatively small proteins compare to legumes seeds. Owing to their wider
amino acid variability compared to legumes as well as cereals, their amino acid
configuration is outstanding, along with superior lysine content 5.1-6.4% in addition to
methionine 0.4-1% content. Quality of protein is used as major aspect for defining the
nutritional value of foodstuff, which is dependent mainly upon its amino acid configuration,
digestibility, and impact allied with anti-nutritional components and also the tryptophan a
huge nonaligned amino acid (Aluko and Monu, 2003). Quinoa is taken into thought as
another source of protein whose nutritional value is equivalent to that of milk protein. It
might be a substitute to cereals in the human foodstuff owing to its wholesome value and
high protein quality. Therefore, its utilization should be encouraged to increase the
nutritional value of food products (Comai et al., 2011).

2.1.4 Lipids

Lipids have an important effect on the texture and quality of foodstuffs for the reason of
their capability to associate with proteins, because of their amphipathic in nature and with
starch where it form inclusion complexes (Goesaert et al., 2005). These are valuable for
fresh functional characteristics of bread, for example high sensory score for softness and
overall acceptability and high specific volume (Angioloni and Collar, 2011). Despite the superior amount and outstanding quality of protein, quinoa seed deliver an interesting lipid content of about 1.8-9.5% (Ryan et al., 2007). The crude fat content of quinoa varied from 4.4% to 8.8%. Whole fat provide 55-63% of two vital fatty acids, linolenic and linoleic acid. 10% of the energy is delivered by the linoleic acid. Moreover, linoleic and linolenic acid ratio of quinoa is also satisfactory (Ruales and Nair, 1993). A regimen containing a higher percentage of linoleic and linolenic acid boosts the pathogenesis of various progressive illnesses, for example bones weakness, heart disease, cancers, as well as inflammatory, in addition to autoimmune ailments. The biological indicators linked to the aforesaid illnesses declines with a higher intake of n-3 fatty acid (Alvarez-Jubete et al., 2009).

Oil of quinoa is full of essential polyunsaturated fatty acids and it has the configuration much like which allied with soybean oil. Quinoa seed have 7% oil content which is higher than corn (4.9%) but lower than soya (20.9%) (Wood et al., 1993). Researchers showed the fatty acid configuration of quinoa fats; the overall monounsaturated contribute 25-28.7%, (oleic acid), total polyunsaturated is 58.3% (linoleic acid) and total saturated contribute 19-12.3% (palmitic acid) (Ryan et al., 2007). In quinoa profile of fatty acid is as good as to soybean oil along with corn oil. Higher quantity of natural antioxidants, specifically 69-75mg α-tocopherol accompanied by 76-93mg γ-tocopherol per 100 grams of quinoa oil were also present. Owing to the best quality oil and amount of raw fat as much as 8.8%, quinoa may possibly also known as the pseudo-oilseed crop plant and might be cultivated for the purpose of oil production (Koziol, 1992). The oil content present in seeds of quinoa ranged from 1.8 to 9.5%, with an ordinary content of 5.0-7.2% that is greater than that of other grain particularly maize seeds oil (3-4%). Oil of quinoa is rich source of essential fatty acids, for example linolenate and linoleate (Koziol, 1990) and have a high contents of natural antioxidants like γ-tocopherol and α-tocopherol (Repo-Carrasco et al., 2003; Bhargava et al., 2006). There is a comparatively high quantity of oil in quinoa, which make it a potential source edible oil (Cusack, 1984). Owing to its lipid fraction it has an excellent balance between fats, oil, and protein content (Ranhotra et al., 1993; Wood et al., 1993; Ryan et al., 2007). Quinoa has lower oil content than soya (20.9% on dry basis) and higher than maize (4.9% dry basis) (Koziol, 1993). The oil is accumulated in the germ, which is about 25-30% of the total weight of the seed (Koziol, 1993; Vidueiros et al., 2013). In quinoa the germ encloses the endosperm and can be
removed without problem by a modified technique to give a portion comprising of 19% oil (Koziol, 1993).

The fatty acid outline of quinoa oil showed that it is rich in \( \alpha \)-linolenic acid and linoleic acid, which are essential metabolism substrates in animal. Eicosapentaeenoic (EPA) and docosahexaenoic acid (DHA) performed key parts in thrombosis which are produced on the metabolism of linoleic acid, atherosclerosis prostaglandin metabolism, membrane function and also in immunology and inflammation (Youdim et al., 2000; Abugoch et al., 2011). Therefore quinoa oil seems to be excellent in the manner of quality, alike to the composition of fatty-acid as soybean and maize oil (James and Lilian, 2009). Providing the superior quality of edible oil and the circumstance that specific varieties of quinoa showed fat content about 9.5% (Koziol, 1993).

Crushed quinoa is liable to increased oxidation of lipid due to the activation of lipolytic enzymes present in the seed and extend surface area, consequently conceding its keeping quality. It is likewise rich source of vitamin E, which is thought to keep it safe from lipids oxidation (Ng et al., 2007). The fatty acid composition of quinoa is alike to the fatty acid profile of soybean and corn oils. Quinoa contain similar quantities of linolenic acid as present in soybean oil. Despite the fact that, high in unsaturated fats, quinoa oil is stable, owing to its high amounts of vitamin E, which act as natural antioxidant to stop rapid lipid oxidation process (Koziol, 1992).

### 2.1.5 MINERALS

Minerals are important constituent perform various functions in the body and are main constituents of muscles, soft tissues, teeth, bones, nerve cells and blood. Minerals are required for various metabolic reactions, regulation of salt and water balance among other functions, transmission of nerve impulses and rigid bone formation (Dini et al., 2008). The human body needs more than 100 mg of each major mineral per day (Na, K, Mg, Ca, S, Cl and P) and less than 100mg of trace elements per day (Mn, Co, Cr, Zn, Fe, Cu, Se, I and Mo) (Hager et al., 2012b). Quinoa grain have more minerals like magnesium, calcium, iron, zinc and copper than common cereals, and its iron content is mostly high. Phosphorus and magnesium are confined in the embryonic tissue, while potassium and calcium are located in the pericarp of quinoa seed (Konishi et al., 2004). The mineral deposits associated with quinoa tend to be focused within the external bran, as with other cereals (Repo-Carrasco et al., 2003). Magnesium, calcium, iron and also phosphorus are present in abundant amount in quinoa. The phytic acid and saponins are the chief components that affect the availability
of these minerals. The copper, manganese, magnesium as well as iron in 100g of quinoa grain provided daily requirements. The calcium content of quinoa seed is greatly decreased by abrasion of seed for saponin removal. It was reported that potassium and calcium are concentrated in pericarp while magnesium and phosphorus were found in embryonic tissue of quinoa (Konishi et al., 2004).

In general, the mineral content of quinoa seed is higher than that of other cereals like barley and oat, particularly for calcium, potassium and magnesium (James and Lilian, 2009). The quantity of minerals like iron, magnesium, copper, and manganese in 100g quinoa seeds is appropriate to cover the daily requirements of infants and adults body, whereas the phosphorus and zinc content present in 100 g of quinoa seeds is enough for requirement of children. Washing and polishing quinoa seeds decrease the mineral content, 27% loss of copper, 3% in magnesium and 12-15% loss in the concentration of iron, zinc and potassium (Jancurova et al., 2009a). It is interesting to note that quinoa exhibits substantial diversity in mineral content (Oshodi et al., 1999; Ogungbenle, 2003; Repo-Carrasco et al., 2003), which may be because of the fact that the mineral content may differ depending on factors such as variety, ripeness, soil type, intensity, exposure time to sunlight, temperature & rainfall and the use of fertilizers (Zielinski and Kozlowska, 2000; Miranda et al., 2009; Miranda et al., 2010).

Ash content of quinoa (3.4%) is reported to be greater than that of other traditional cereals like wheat (1.8%) and rice (0.5%) (Bhargava et al., 2006). Quinoa possess enormous content of minerals such as Zn (Zinc), Fe (iron), Cu (copper) and Mn (Manganese) (Repo-Carrasco et al., 2003). Calcium (874 mg/kg) and iron (81 mg/kg) in the quinoa seeds are comparatively in higher contents than most of commonly utilizing cereal crops (Ruales and Nair, 1992). Minerals like Mg, P and K are found in the embryo, whilst Ca and Pare located in pericarp and are linked with cell wall. The abundant mineral content makes the grains valuable for children and adults to fulfill the mineral requirement specially calcium for their bones development and iron for different functions of blood (Konishi et al., 2004).

2.1.6 VITAMINS

Pseudo-cereals (amaranth, buckwheat, and quinoa) are convenient for the healthy lifestyle and appropriate nutrition. Quinoa possesses comparatively high quantities of vitamins (vitamin C, thiamin,) and minerals. Quinoa is a rich source of folic acid, thiamin and vitamin C. The quinoa seeds have double as much γ-tocopherol (5.3mg/100g) as compared to α-tocopherol about which informed to be 2.6 mg/100g (Jancurova et al., 2009a). The
amount of folic acid and vitamin B₆ in 100g of seeds are enough to fulfill the daily needs of children and adults body. The vitamin B₂ content in 100g of quinoa seeds give up to 80% of the daily requirement of children and 40% of those of adults. The vitamin B₃ content in quinoa seeds is useful to the diet, even if its quantity does not fulfill the daily needs of the body (James and Lilian, 2009). Vitamin B₁ content in quinoa seeds are comparatively less than those of cereals especially in barley or oats, on the other hand vitamin B₂, B₃, B₆ and total folate are higher (Ranhotra et al., 1993).

The vitamin configuration linked with quinoa is as good as the cereals. The quinoa seeds have better amount of riboflavin ranged from 0.30 to 0.32 %, vitamin B₆ about 0.48 %, total folate (0.18%), and thiamin (0.29-0.36%) (Taylor and Parker, 2002). In quinoa seeds, ascorbic acid to be found in amounts ranged from 4.0 to 16.4g/100g (Rondan-Sanabria et al., 2012). Furthermore, it has been found to be good source of other vitamins like vitamin E, which act as natural antioxidant and source of γ-tocopherols (5.3mg/100g) as well. Because of good carcinogenic potential and anti-inflammatory actions, the γ-tocopherol is of great biological significance (Alvarez-Jubete et al., 2009).

Quinoa and amaranth hold high content of total folate about quinoa have 132.7mg/100g and amaranth have 52.8 to 73.0mg/100g on dry weight basis respectively which is ten times more as present in wheat. The bran fraction of seeds contain on around 124% of total folic acid, while remaining fractions of seeds contained only 57%. On storage for three months about 34% loss of folate was observed in flour, 16% in cookies about 24% in noodles and, 51% in bread. Regardless of these losses, content of total folate was found to be in range of 18-62mg/100g in cookies, 17-98mg/100g in noodles, and 26-41mg/100g in breads on dry weight basis. The vitamin composition of quinoa is attractive because of elevated amount of total folate and vitamins B₆ which can be enough to fulfil daily needs of kids and adults. The flour fractions contained on an average only 57% total folate, while 124% have been found to be present in the bran fractions (Schoenlechner et al., 2010a). In comparison with other cereals quinoa has lesser amount of thiamin but quinoa have comparatively have higher riboflavin, total folate, niacin and vitamin B₆. The 100g of quinoa contained sufficient amount of riboflavin that can covers the 80% of kids and 40% of adults requirement (Repo-Carrasco et al., 2003).

2.2 Polyphenols and bioactive components

Quinoa have bioactive compounds in higher concentration such as squalene (3.39-5.84%), which is known as the biochemical precursor of steroids group and for unsaturated open
chain triterpene (Jahaniaval et al., 2000). Being a food constituent, squalene give the competency to reduce cholesterol level in the body through preventing the cholesterol synthesis inside the liver (Sindhuja et al., 2005). Polyphenols are plant metabolites existing in largely utilized foodstuff made from plant sources. Phenolic acid, flavonoids and tannins are three main sort of polyphenols which act as leading antioxidants (Hirose et al., 2010; Repo-Carrasco-Valencia et al., 2010a). Polyphenols are pervasive in plant foods and possess numerous potential useful effects on the human health, for instance, decrease of various risks like neurodegenerative diseases, cancers, diabetes, cardio-vascular diseases, Alzheimer’s and osteoporosis diseases (Youdim et al., 2000; Kurosawa et al., 2005; Repo-Carrasco-Valencia et al., 2010a).

Polyphenols may give flavor, bitterness, color, acidity and oxidative strength to foodstuffs (Shahidi and Naczk, 1995; Scalbert et al., 2005; Han et al., 2007). Gorinstein et al. (2008) reported 251.5±22.2μg/g of ferulic acid, 1.1±0.1μg/g of p-coumaric acid and 6.31±0.5μg/g of caffeic acid in quinoa. Repo-Carrasco-Valencia et al. (2010a) found that the levels of betalains, flavonoids and phenolic acids in grains of pseudo-cereal. The phenolic acids contents are ranging from 16.80-59.70 mg/100 g among this the quantity of soluble phenolic acids varied from 7-61%. It was concluded that phenolic acid content were low than other cereals crops such as rye and wheat but were at par with that of rice, barley, oat and corn. In quinoa kaempferol and quercetin found as major flavonoids, however in some quinoa varieties isorhamnetin and myricetin have been reported. Quinoa grains might also be considered as brilliant source of flavonoids (Shahidi and Naczk, 1995). Meanwhile dietary flavonoids are considered to have health promoting benefits, probably due to their anti-inflammatory and antioxidant characteristics, it can be securely said that Andean native crops like quinoa have tremendous health endorsing potential rich in bioactive components as flavonoids (Hirose et al., 2010).

Pseudo-cereal flour and breads were evaluated for their phenolic acid content, buckwheat flour showed the highest phenolic contents which were found to be 7.25±0.23mg/g on dry weight basis. While the bread have flavonoids 2-4 times less as compared to flour. The addition of buckwheat flour to wheat flour for bread preparation at higher level have more effect by improving antioxidant activity which was improved by 2.36 to 3.64times as compared to breads prepared from quinoa and amaranth flour at higher level (Chlopicka et al., 2012).

2.3 Antioxidant property of quinoa
Quinoa antioxidant activity may be of particular interest for scientists and needs consideration for its utilization as a powerful source of antioxidant (Schoenlechner et al., 2010b). Asao and Watanabe (2010) use barley, foxtail, Japanese millet, buckwheat, millet, wheat along with rice and compared for antihypertensive reaction, antioxidant action and allergenicity with quinoa and amaranth. It has been concluded that pseudo-cereals possessed more powerful radical scavenging capability, the significant scavenging capability regarding amaranth and quinoa have been 22.6 and 49.3mg gallic acid/g respectively. The angiotensin converting enzyme (ACE) retardion action of quinoa was similar to buckwheat. The amaranth showed higher ACE inhibition action than wheat as well as rice.

The antioxidant properties and flavonoid composition of quinoa seed grown in Japan were analyzed and compared with conventionally grown cereals and pseudo-cereals. The crude extracts of quinoa showed greater antioxidant properties than buckwheat. Being the good source of bioactive flavonoids and antioxidant among pseudo-cereals and cereals, the quinoa seeds were the most efficient functional food (Tomoskozi et al., 2011). Chlopicka et al. (2012) prepared breads by replacing straight grade wheat flour with 15% and 30% of pseudo-cereal flours (quinoa, amaranth and buckwheat) and evaluated the bread for its antioxidant properties and sensory quality. It was observed that buckwheat flour possess comparatively high phenolic content (7.25+0.23mg/g). The composite flours contained 2-4 times more total flavonoids as compare to breads when replaced with pseudo-cereal. The improving in antioxidant activity of wheat breads especially at higher level of buckwheat flour was assessed through FRAP as well as DPPH, that indicate increase 2.36% and 3.64% respectively as compare to flour substituted at lower level of buckwheat flour, in contrast to other pseudo-cereals (quinoa, amaranth), with the addition of higher level showed 1.20-1.79 and 0.60-1.71times more as compare to composite flour prepared with buckwheat.

2.4 Anti-nutritional components

Anti-nutritional components are those components that have the ability to undesirably effect on health and growth by inhibiting the absorption of nutrients from food (Soetan and Oyewole, 2009). The intensities of anti-nutritional components in plants differ with the cultivar, species and postharvest techniques (Soetan and Oyewole, 2009). Various anti-nutritional elements reported in quinoa, for example, phytic acid, tannins and saponins that have a negative impact on the performance of monogastrics (Improta and Kellems, 2001). Following anti-nutritional components have been reported in the seeds of quinoa,
- Saponins
- Phytic acid
- Protease inhibitors
- Tannins

2.4.1 Saponins

Saponins are sterols or glycosidic triterpenoids existing in several plants. The word saponin is derived from Latin word meaning soap, have capability of making foams on mixing and stirring in water (Taylor and Parker, 2002). Triterpene saponins found almost in all parts of quinoa plant, for example, in leaves, blossoms, seeds and seed coats (Mastebroek et al., 2002; Kuljanabaghavad et al., 2008). These saponins are drawback for quinoa as a food and feed application because these impart bitter taste and represent the major anti-nutritional factor found in the grain (Ma et al., 1989). Koziol (1992) categorized the quinoa as "sweet" or "bitter" on the basis of saponin concentration. Quinoa in which saponin is less than 0.11% or absent on a fresh weight basis is known as sweet quinoa on the other hand the quinoa varieties that have saponin content more than 0.11% on fresh basis is known as bitter quinoa. The content of saponin varied in seeds of both bitter and sweet genotypes from 4.7 to 11.3 and 0.2 to 0.4g/kg on dry weight basis respectively (Mastebroek et al., 2002).

Saponin having an aldehyde group, glucose, arabinose, glucuronic acid and galactose which are attached at C-3 of quinoa saponin. (Bhargava et al., 2006; Kuljanabaghavad et al., 2008). Saponins present in quinoa seeds can be removed by the wet process such as washing and rubbing in tab water or either by the dry method in which removal of seed coat by toasting and consequent rubbing of the grains (Risi and Galwey, 1991). Abrasive dehulling is also used in industries for saponin removal (Reichert et al., 1983) by this method saponins remains attached with perisperm (Becker and Hanners, 1990). Saponin elimination by rubbing and cleaning with water had a small impact on loss of vitamin contents. This method can destroy thiamin content up to 30%, folic acids 15% as well as α-tocopherol 5%. Saponin removal by the toasting, used in dry method can loss mineral and vitamin contents at some extent, the loss being significant in the case of iron, potassium, and manganese (Ruales and Nair, 1993).

The saponin concentration of quinoa fluctuates with environmental conditions and variety (Koziol, 1992; Repo-Carrasco et al., 2003). It is also significantly affected by soil-water insufficiency (Soliz-Guerrero et al., 2002). Thermal treatment of quinoa flour can also
effect in degradation of saponin molecules. Saponin decomposition may affect pharmacological or sensory characteristics (Brady et al., 2007). Saponins have the capability to solubilize in methanol and water molecules like detergent that consist of sugar chains which are hydrophilic and are attached with the triterpenoid aglycones which are lipophilic. The quinoa saponins resulting three main triterpenes or sterols named as sapogenins which are oleanolic acid phytoaccagenic acid and hederagenin (Koziol, 1992). Chauhan et al. (1999) narrated that maximum about 34% of saponins were existing in the bran portion of seed. Moreover, they were of the opinion that saponins were two fold in the perisperm. It has been discovered that saponin have drawback that can lead damage to mucosal cell wall by varying cell permeability of membrane and also effect the transportation of nutrients.

The quantity of toxic constituent in saponins depends upon its own structure, subjected objects and the way of contact. The side effects of prolonged use of saponins are unaware. Although saponins are commonly observed as antinutritional materials which hinder the consumption of quinoa. Such as there is great medicinal interest about saponins for their proficiency to help in the absorption of specific medicines in addition to their own hypocholesterolemic characteristics (Ridout et al., 1991). Sweet varieties tend to be rather more suitable from consumer perspective as they are less susceptibility to the attack of birds and pests (Fleming and Sosulski, 1977). Oakenfull and Sidhu (1990) documented that saponins had little impact on intestinal tract penetrability, which might help in absorption of particular medicines, therefore making medicinal curiosity in the activities of saponins within the body.

2.4.2 Phytic acid/ protease / trypsin inhibitors and tannins

Phytic acid (C₆H₁₈O₂₄P₆) recognized as inositol hexaphosphate (IP6) or phytate (Jacela et al., 2010), an abundant constituent in plants in the form of phosphorous (P) specially in cereal and legume seeds, existing as mixed salts (phytates) of mineral cations, including minor amounts of Zn and Fe (Lott et al., 2000; Raboy, 2001; Ma et al., 2006). Most of the P and minerals in these salts cannot be utilized by monogastic animals (Ma et al., 2006). Phytate is commonly recognized as a substance that decrease the absorption of minerals however, it is also as a potential useful vitamin-like constituent (Szkudelski, 2005), phytate-phosphorus is available nutritionally in a smaller amount since the phytate is not quantitatively hydrolysable in gut of human (Sandberg and Andlid, 2002; Coulibaly and Chen, 2011).
Phytic acid in quinoa, present in the external layers similarly as in wheat and rye and also uniformly spread in the endosperm of seed, which is in sharp contrast to other cereals crops where it is accumulated in the seed germ. In quinoa, 60% of the total phytate is accumulated in the embryo, 35% in the perisperm and 5% in the bran (Ahamed et al., 1998; Ando et al., 2002). Koziol (1992) described that phytic acid content in quinoa seeds ranged from 10.5 to 13.5mg/g in different varieties, which was in the range of 7.6–14.7mg/g similar as existing in other cereals crops. Valencia et al. (1999) deduced that different treatments like soaking of seeds, lactic fermentation and germination of quinoa seed have improved iron solubility while reduced to phytate content. On the other hand fermentation of germinated quinoa flour was most effective for reducing the level of phytate, which was found to be totally hydrolysed and the solubility of iron was also increased up to eight times as compared to unfermented quinoa flour (Lindeboom et al., 2005b; Bhargava and Srivastava, 2013). Phytates might develop unsolvable complexes with multivariate cations i.e. Mg$^{2+}$, Fe$^{2+}$, Fe$^{3+}$, Ca$^{2+}$, as well as Zn$^{2+}$ within the gastrointestinal system, therefore decreasing their bioavailability (Serraino et al., 1985).

The level of protease in the seed of quinoa were observed less than 50ppm. It have been earlier reported that other inhibitors like trypsin are in low content as compared to the grain of other commonly used cereal crops. Other inhibitors like trypsin and tannin are present in very minute concentration. As for as tannins in whole quinoa seeds as flavonols were reported about 0.5% (Ahamed et al., 1998; Improta and Kellems, 2001).

2.5 Rheological, baking and properties of quinoa

By using farinograph dough rheological properties prepared from wheat flour with addition of buckwheat and quinoa flour (2.5%, 5.0%, 7.5%, and 10%) were studied and matched with dough of straight grade wheat flour. Dough prepared from buckwheat flour addition was less stable than dough prepared from quinoa flour. There is also significant differences were seen in dough growth time. By using high buckwheat flour amount in dough minimized dough growth time but its affect was negligible in case of quinoa flour addition (Jancurova et al., 2009b).

Flour of quinoa have various functional characteristics such as water binding capacity, solubility, foaming and emulsion capacity which make it diversified to use in various products (Bilalis et al., 2012). In addition quinoa has been supposed as oil seed crop owing to it oil composition which have interesting concentration of fatty acid like omega-6 and prominent content of vitamin E. Moreover, physic-chemical properties of quinoa starch
make it appropriate for innovative uses. It is consider as promising alternative crop owning to its tremendous nutritional profile and utilized as novel functional food (James and Lilian, 2009).

The effect of protein isolates, isolated from amaranth and quinoa flour on rheological properties of bread and wheat flour were investigated. Rheological properties did not change significantly by adding 10% quinoa or amaranth flours. Though their degree of softening, stability and elasticity significantly changed by the addition of greater amount (20% and 30%). The water absorption capacity was increased by the substitution of wheat flour by quinoa or amaranth flours. By using mixtures of high percentages of quinoa or amaranth flour in bread a significant increase of resistance to deformation of crumb was observed and there is also decline occurred in specific volume. Rheological properties of bread crumb and dough did not changed significantly with the addition of protein isolates (Tomoskozi et al., 2011).

A wide range of gluten-free flours are available as alternative to wheat flour. Breads produced from gluten free flour are often low in nutritional quality and show poor sensory characteristics such as dry crumb, poor mouth feel and off flavors (Gallagher et al., 2004; Hager et al., 2012b). Most gluten-free formulations include gluten-free starches, hydrocolloids and protein-based ingredients which mimic the viscoelastic characteristics of gluten (Gallagher et al., 2004). Sourdough containing quinoa showed significantly increased dough strengths (Wolter et al., 2014). The diversified utilization of quinoa flour is possible only due to its functional properties like water-holding capacity and emulsifying capacity. Quinoa starch provides physicochemical attributes for example viscosity and freeze stability, which usually offer its useful properties along with its utilization as novel ingredient (James and Lilian, 2009). Various processing procedures have been utilized for a long time to rise the amount of bioactive components and the subsequent utilization of flavoring compounds obtained from pseudo-cereals. The distinguishing flavoring compounds in the products of the pseudo-cereals combined with their stability with respect to the impact on the overall aroma of product (Lasekan and Lasekan, 2012).

The addition of pseudo-cereal (quinoa and buckwheat) seeds (at levels of 30% and 40%) resulted in a valuable impact on nutritional importance of breads. In assessment with the wheat bread that was used as control sample, the protein increase about 2% and the increase of crude fiber content at around 0.5% in 30% supplemented breads were reported. Furthermore, the incorporation of both quinoa and buckwheat mixture at the level of 40%
increased the content of protein for 2.5% and fiber content for 0.4%. The results showed that the blends containing either 30% or 40% of particular seeds articulated higher potential for the making of molded breads, as new baking products with enhanced nutritional composition (Demin et al., 2013). Cereal based products like pasta, bread, biscuits are getting attention and an increasing trend has been observed in the use of pseudo-cereals for the formulation of high quality, gluten free and nutritionally rich products. But there is a major issue of their commercialization of such products as it is still limited. Nutritionally rich products will be available if the products made from pseudo-cereals are made available in the market for masses (Alvarez-Jubete et al., 2010b).

Rheological properties of the dough have been improved by adding 20% dehulled quinoa seeds which are devoid of saponins and by their addition positive effects have been observed on wheat bread dough and this also play an important role in 2% increment of protein content in bread. An excellent supplementation results were observed in sensory characteristics of breads at a rate of 20%. New and wide range of products can be attained by the development of bakery products made from the supplementation of wheat flour with quinoa seed flour (Stikic et al., 2012).

Quinoa seeds were mixed with wheat flour to study their effect on bread making ability. After the investigation, it was inferred that for bread making 10% substitution of wheat flour with quinoa flour was found acceptable on loaf volume, structure, weight, loaf volume, texture, dough stability, color and taste (Lorenz and Coulter, 1991; Enriquez et al., 2003). From these results a range was declared about 20-30% that can be added in baked products but sometimes a bitter after taste has been reported. However, proper and efficient sensory evaluation has showed that bitter after taste may be due to poor processing of seeds. By keeping in mind these observations, 10% addition was found up to the mark and good in sensory parameters (Stikic et al., 2012).

Various studies have been carried out for the preparation of gluten free pasta by using buckwheat, amaranth and quinoa. After the investigation, results obtained showed that increased cooking loss was observed in the quinoa pasta while decreased texture firmness and cooking time was observed in pasta made from amaranth. On the other hand least negative effect was observed in pasta made from buckwheat. However by blending all three combination of raw materials to one flour in the ratio in such a way that maximum quantity of buckwheat which is 60% followed by 20% of both quinoa and amaranth which resulted in the improvement of dough matrix. By the addition of 6% egg white and 1.2% emulsifier
and by decreasing dough moisture up to 30% cooking time as well as firmness has been increased and reached to acceptable level (Schoenlechner et al., 2010a).

Pseudo-cereals i.e. quinoa, buckwheat and amaranth can be used as potential source of health and high-quality seed producing crops was investigated as ingredients in gluten free breads. Volume of bread were evaluated which prove increase significantly by the addition of the quinoa and buckwheat flour in the breads as compare with the control (wheat flour bread). Furthermore, the pseudo-cereal like quinoa wheat and buckwheat flour comprising breads were characterized by a significantly softer texture of crumb effect which was attributed to the existence of natural emulsifiers in the pseudo-cereal flours and this property is evaluated by the confocal images of the flour. No significant differences were attained in the suitability of the gluten free bread contains flour of pseudo-cereal in comparison with the control (whole wheat flour) bread (Alvarez-Jubete et al., 2010b).

Sensory studies of bread have shown that there is an improved and increased impact have been found by the buckwheat flour addition of to the wheat flour on various parameters like color, taste and odor. From this it was concluded that buckwheat flour addition can increase the physical properties like sensory and chemical properties which is antioxidant. Breads made from these different pseudo-cereals like buckwheat and quinoa can be commercialize as functional foods (Chlopicka et al., 2012).
CHAPTER 3 MATERIALS AND METHODS

3.1 Procurement of raw material

Four lines of quinoa named *C. quinoa* V7, *C. quinoa* V2, *C. quinoa* V9, *C. quinoa* V1, were procured from Department of Crop Physiology, University of Agriculture, Faisalabad. Wheat were purchased from AARI, Faisalabad (Wheat Research Institute).

3.2 Physical properties

Different physical properties of the quinoa were measured as given below:

3.2.1 Thousand grain weight

The thousand grain weight was determined by weighing the weight of 100 seeds in triplicate and then extrapolating this weight to weight of 1000 seeds (Vilche *et al.*, 2003).

3.3 Milling

3.3.1 Milling of quinoa

All quinoa samples were grinded in a hammer mill.

3.3.2 Milling of wheat

The grains were tempered at moisture content at the level of 14.5%. The water required for tempering of seed was measured by following the procedure given in AACC (2000) method No. 26-95.

\[
\text{Amount of water (mL) required} = \frac{100 - \text{Original Moisture(\%)}}{100 - \text{Desired Moisture(\%)}} \times \text{Weight of Sample}
\]

3.4 Chemical analyses

The quinoa flour sample was evaluated for proximate composition such as moisture, crude protein, crude fiber, crude fat and ash content as well as bread was evaluated for its moisture, protein, ash and fat content according to their respective methods as given below.

3.4.1 Moisture content

Moisture content of the sample were calculated by using the procedure described as in AACC (2000) method No. 44-15A. Different weighed samples were taken into separate crucibles and placed in hot air oven at 105°C for 24 hours. After 24 hours dried samples were taken out and weighed after cooling in desiccators for 5-10 minutes. Then the sample was again placed in oven till constant weight. The following formula was used to calculate the percentage of moisture.
Moisture (%) = \frac{\text{Wt. of Original Sample (g)} - \text{Wt. of Dried Sample (g)}}{\text{Wt. of Original Sample (g)}} \times 100

3.4.2  Crude protein content

Protein content in the samples was determined by using Kjeldahl’s method as described in AACC (2000) method No 46-10. For this purpose, 2g of dried sample was taken into a digestion flask and digested with 30mL concentrated H₂SO₄ including 1 digestion tablet till transparent digested material was obtained. The digested material was then diluted to a volume of 250ml and 10mL of diluted sample was distilled with 40% NaOH in a distillation apparatus. The ammonia thus liberated was condensed and entrapped in boric acid (4%) solution having methyl red which was used as an indicator. The distillate was then titrated against standard 0.1N H₂SO₄ solution taken in the burette until golden yellow end point.

\[
\text{Nitrogen} (%) = \frac{\text{Volume of 0.1 N H}_2\text{SO}_4 \text{ used} \times 0.0014 \times 250}{\text{Weight of sample} \times \text{Vol. of sample (10ml)}} \times 100
\]

Crude protein content = \text{ N %} \times 6.25

3.4.3  Crude fat content

The soxhelt apparatus was used for the determination of crude fat in each sample according to AACC (2000) method No. 30-25. For the purpose, 5g of sample was extracted with petroleum ether at a condensation rate of 2-3 drops/sec. for approximately 8hrs or 5-7 washings. After distilling excess ether residue in extraction flask was dried at 100°C for 30 min. until a constant weight. Fat content was measured by using the formula given below.

\[
\text{Fat} (%) = \frac{\text{Weight of Ether Extract}}{\text{Weight of sample}} \times 100
\]

3.4.4  Crude fiber content

Samples after fat extraction were used for crude fiber content by following the procedure mentioned in AACC (2000) method No. 32-10. 2g dried and fat free sample was taken in a 500mL capacity beaker and 200mL of 1.25% H₂SO₄ was added and the level of beaker was marked. The contents of the beaker were boiled for 30 minutes. Contents were filtered and subjected to 2-3 washings with warmed water (150mL) to make it acid free. The retentate was shifted to a 500mL beaker again and 200mL of 1.25% NaOH was added into it. The contents were again boiled for 30 minutes, filtered and 2-3 washings with hot water were
given until alkali free. The retentate was carefully shifted to a weighed crucible and dried in an oven at 100°C for 3-4 hours until constant weight was obtained. The contents were heated on flame until the smoke ceased to come out of the sample. At that point the sample was placed in a muffle furnace at temperature of 550°C for for time period of 4 hours until a grey ash was obtained, then the resultant was cooled by placing in desiccator and again weighed. The difference in weight was calculated as crude fiber by using under discussed formula:

\[
\text{Crude fiber (\%) = \frac{\text{Loss in Weight on Ignition}}{\text{Sample weight (g)}} \times 100}
\]

### 3.4.5 Ash content

Each sample was tested for ash content by following the procedure described in AACC (2000) method No. 08-01. The samples were taken in pre-weighed oven dried crucibles and charred on the burner before incinerating in the muffle furnace where a temperature of 550°C was maintained till the sample converted to grayish white residue.

\[
\text{Ash (\%) = \frac{\text{Weight of Residue}}{\text{Weight of Sample}} \times 100}
\]

### 3.5 Determination of mineral content

The samples were investigated for their mineral profile after wet digestion in di-acid mixture of HNO₃:HCLO₄ in the ratio 7:3 by following the guidelines given in AOAC (2006). For the assessment of sodium (Na) and potassium (K), Flame Photometer-410 (Sherwood Scientific Ltd.) was used. Likewise, Atomic Absorption Spectrophotometer was run for the measurement of magnesium (Mg), zinc (Zn), calcium (Ca), copper (Cu), manganese (Mn) and iron (Fe). ICP-MS was used for determination of the trace elements (Nascimento *et al.*, 2014).

### 3.6 Determination of quinoa fatty acid profile through GC-FID

Fatty acid profile of quinoa was carried out by following the method as described by Przybylski *et al.* (1994) with some modifications. Oil from the quinoa was extracted through soxhlet extraction method by using hexane as solvent. Fatty acid methyl esters were prepared by following the process given by Ryan *et al.* (2007). About 40mg of oil was treated for 15 min by 1 ml methanolic NaOH at the temperature of 100°C by using Pyrex culture tube closed with screw cap. The tubes were cooled by using ice, after cooling 2 ml boron tri-fluoride was added and boiled for further 15min. Again tubes were cooled down by using ice, then in cooled mixture about 1 ml of isooctane along with 2
ml saturated solution of NaCl were added in tubes and dissolved by shaken vigorously
and the mixture was separated into layers after allowing the tubes to stand for specific time.
From the Pyrex tube upper layer of hexane having the fatty acid methyl ester was
collected and shifted to vial and kept at -20°C till further investigation. For fatty acid
methyl ester (FAME) analysis DB-WAX column was used. The column was linked to a
Gas chromatograph which was attached with a FID detector. Furthermore, the nitrogen
gas was utilized as carrier gas. The temperature program was set as follows: Inlet
temperature, 250 °C, detector temperature 285°C, column temperature start at 100°C,
10°C/min to 180°C, hold 5 min, than 5°C to 240°C hold 25min. Auto sampler set for 3
sample rinses while after injection with 3 solvent rinses. Standard of fatty acid were run to
determine the fatty acid profile of quinoa.

3.7 Preparation of quinoa protein isolates
Quinoa protein isolates were prepared by following the method demonstrated by Aludatt et al. (2012). 10 g of quinoa flour were blend with 100ml of 2N NaOH. The pH of blend was
adjusted at 11.0 and mixture was mixed at 23°C for 60 min in a water bath, and then
centrifuged at 10,000g for 15min. The cheese cloth was use to filtered the extract. The pH
of supernatant was adjusted to 4.6 by using 0.1 N HCl. The proteins were precipitated and
separated by using centrifugation and resulted protein were freeze dried for further analysis.

3.8 Functional properties of quinoa protein isolates
Functional properties of quinoa protein isolates such as water absorption capacity, oil
absorption capacity, emulsifying capacity, foaming capacity (FC) and foam stability (FS)
was determined according to their respective procedures.

3.8.1 Water absorption capacity (WAC)
The method used for determination of water absorption capacity of quinoa protein isolates
was followed as described by Tomotake et al. (2002). 5g of protein isolates was taken in
already weighed centrifuge tubes. Distilled water was added in each sample under
continuous stirring by using glass rod until sample was wetted completely after that samples
were centrifuged. After the centrifugation of samples, the amount of distilled water seprated
as supernatant in the tube was measured. Lastly water absorption capacity was calculated
by using following formula.

\[ \text{WAC} = \frac{(W_2 - W_1)}{W_0} \]

Where: \( W_0 \) = Dry sample weight (g)
\( W_1 \) = Weight of dry sample and the tube (g), \( W_2 \) = Weight of sediments along with tube (g)
3.8.2 Oil absorption capacity

Oil absorption capacity was calculated by following the procedure of Sze-Tao and Sathe (2000) with some modification. Sample of protein isolates about 0.5 g along with 3.0 mL of corn oil was blended and mix for 1 min. After holding for 30 min, furthermore the blend was centrifuged at 3000g for 20 min. oil absorption capacity was presented as the percentage of oil confined by the protein isolates. Oil absorption capacity was calculated by using following formula.

\[
\text{Oil Absorption Capacity} = \frac{(F_2 - F_1)}{F_0}
\]

Where: 
- \(F_0\) = Weight of sample on dry weight basis (g), 
- \(F_1\) = Weight of sample on dry basis along with tube (g), 
- \(F_2\) = Weight of the tube plus the sediment (g)

3.8.3 Emulsion capacity (EC)

Emulsion capacity of quinoa protein isolate were calculated by following to the method discussed by Pearce and Kinsella (1978). It was determined by following mentioned equation:

\[
\text{EC (\%)} = \frac{\text{Height of the emulsified layer (cm)}}{\text{Total height (cm)}} \times 100
\]

3.8.4 Foaming capacity (FC)

Foaming capacity (FC) was calculated according to the procedure discussed by Eltayeb et al. (2011). Foaming capacity (\%) was calculated by following equation:

\[
\text{FC (\%)} = \frac{(\text{Volume After Homogenization} - \text{Volume Before Homogenization})}{\text{Volume Before Homogenization}} \times 100
\]

3.9 In-vitro quinoa digestibility protein

In vitro digestibility of quinoa protein was calculated by using the method as discussed by Tinus et al. (2012). Quinoa sample equal to 62.5 mg of protein were taken and weighed sample was rehydrated in 10 mL of milli-Q water at the temperature of 37°C for 1 hour. after rehydration the pH of sample was adjusted around 8.0 by using 0.1 M NaOH along with 0.1 M HCl. 10 mL of fresh multi-enzyme solution containing of about 16 mg of trypsin, 31 mg of chymotrypsin and 13 mg protease were prepared on the day of analysis.
and kept at 37 °C and pH of solution were maintained by using 0.1 M NaOH as well as 0.1 M HCl. The enzymes and casein were purchased from Sigma (Sigma Aldrich). After rehydration, 1 mL of the multi-enzyme solution was added to the sample, and the pH of the digesta or dispersion was noted after every 5 second for 15 min. The change in pH at 10 min of digestion sample was used to determine the percent in vitro protein digestibility (IVPD) by using following equation:

\[
\text{In-vitro Protein Digestibility (IVPD)} = 65.66 + 18.10 \Delta \text{pH}
\]

### 3.10 Determination of total starch

Total starch of the quinoa flour was determine by following the procedure of Sopade and Gidley (2009) as given below.

#### 3.10.1 Procedure

This procedure based on Megazyme kit method (AA/AMG 11/01). Weighed 0.05g of the sample, wet the sample by using 0.4 mL of the 80% ethanol, mix and add 2 mL of the dimethyl sulfoxide (DMSO) before heating the mixture in a boiling water bath for 5 min. (shake vigorously at 3 min. to disperse and solubilize gelatinized starch). Added 3 mL of the α-amylase (thermostable) in MOPS buffer and heat in the boiling water bath for 12 min. (shake vigorously at 3, 6 and 9 min.). Add 4 mL of the sodium acetate buffer, mix and equilibrate at 50°C for 2 min. before incubating with 0.1 mL of the amyloglucosidase at 50°C for 30 min. (mix at 10 and 20 min.). Make up to 25 mL volume with water and centrifuge an aliquot. Pipette 50μL of the supernatant, add 1 mL of the enzymatic glucose reagent, incubate in the dark for 20 min. and measured the absorbance at 505nm against a sample blank to know the amount of glucose released. Calculate the total starch content, Ss, of sample (% solids) as:

\[
S_s = 9 \times (A-I) \times V_t / S \times V_a \times W_s [100-M]
\]

Where A = absorbance at 505 nm, I = intercept of the glucose calibration curve, \( V_i \) = total volume (mL) of the digests prior to centrifugation (25 mL), S = slope of the glucose calibration curve in \( \mu g^{-1} \), \( V_s \) = volume (mL) of the supernatant used in the absorbance measurement (0.05 mL), \( W_s \) = weight of sample (50 mg), \( M \) = sample moisture(%), and 9 = a relation (10 x 0.9) of the constant (stoichiometric) for starch from glucose contents.

### 3.11 In-vitro starch digestion

In-vitro starch digestion of quinoa was conducted according to the procedure described by Sopade and Gidley (2009). For that purpose 500mg of the flour sample were treated with 1
37 mL porcine amylase (artificial saliva) for the time period of 15 to 20 seconds after the addition of artificial saliva 5 mL of pepsin was added and the mixture was incubated at the temperature about 37°C for the time period of 30 min by using water bath which was reciprocating at 85 rpm. The mixture (digesta) was neutralized by using 0.02 M NaOH and pH was adjusted to 6 before the adding the 5 mL from mixture of pancreatin and amylglucosidase. In the meanwhile mixture (digesta) was incubated in water bath having temperature about 37°C for the time period of 4 hours, during incubation the concentration of glucose in the mixture (digesta) was determined by using a glucometer (Accu-Check® Performa®) at particular time periods for the rapid determination procedure. At the end of procedure the digested starch in the sample was calculated by using the following Equation:

\[
\text{Digested Starch (DS)} = \frac{G_G \times V \times 180 \times 0.9}{W \times S [100-M]}
\]

In the equation : \(G_G\) indicating the reading of glucometer (mM/L), \(V\) stand for digesta volume (mL), 180 was used for molecular weight of glucose, \(W\) representing the sample weight (g), \(S\) showing the starch content of sample (g per 100 g dry weight basis), \(M\) used for moisture content of testing sample (g per 100 g sample), 0.9 is stoichiometric constant value for starch from glucose contents.

### 3.12 Determination of gelatinization properties quinoa

Gelatinisation properties of quinoa flour were evaluated with the help Differential Scanning Calorimeter by following the process as discussed by Waramboi et al. (2011) the quinoa samples were hermetically sealed in excess water in the ratio of 1:4 keeping a total weight of aluminium pans about 20-25 mg. Furthermore at room temperature the samples were equilibrated for 1 h. For reference aluminium pan (empty) was used before isothermal treatment at 30°C for 5 min. and scanning at 10 °C/min to 120 °C and the onset temperature (\(T_o\)), peak temperature (\(T_p\)) and end temperature (\(T_e\)) as well as enthalpy of gelatinisation (\(\Delta H_{GEL}, \ J/g\)) were determined by using TA Universal Analysis 2000™ software (Mahasukkhonthachat et al., 2010).

### 3.13 Determination of pasting properties

Pasting properties of quinoa flour sample dispersion of 10% w/w solid were determined by following the method as discussed by Mahasukkhonthachat et al. (2010) by using the rapid visco-analyzer. Total weight of 25 g were taken in the RVA canister. Moreover the dispersions were stirred for 10 s at 50°C and 960 rpm, furthermore the dispersion were stirred for an additional 50 s at the same temperature and 160 rpm, after that the dispersion
was heated to 95°C in 3 min, for next 42 s, held at 95°C for 2 min 30 s. Afterward dispersion were cooling down to 50°C in 3 min 48 s, and held at 50°C for 2 min. The RVA Thermocline™ software was used to obtain the pasting properties of samples.

3.14 Preparation of composite flour

The composite flour of wheat and quinoa flour was prepared according to following plan.

**Table 3.1 Treatment plan for composite flour**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Wheat flour (%)</th>
<th>Quinoa Flour (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>T1</td>
<td>95</td>
<td>05</td>
</tr>
<tr>
<td>T2</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>T3</td>
<td>85</td>
<td>15</td>
</tr>
<tr>
<td>T4</td>
<td>80</td>
<td>20</td>
</tr>
</tbody>
</table>

3.15 Dough rheology

Dough rheology was determined using farinograph and mixograph by following the procedures given in AACC (2000).

3.15.1 Farinographic studies

The physical dough characteristics of wheat flour were measured by using Farinograph according to the procedure of AACC (2000) method No. 54-21. The farinogram was interpreted for different characteristics such as dough development time, water absorption, dough stability, softening of dough and mixing tolerance index. 50g composite flour, on 14% moisture basis was kept in the bowl and water was added during mixing from the burette to give a dough stability of 500 BU and described parameters were determined from the farinogram formed.

3.15.2 Water absorption

Water absorption of flour is the amount of water required to reach at the center of the curve on the 500 Brabender Units (BU) line with maximum consistency of the dough (peak). For each treatment water absorption was recorded directly from the burette attached to the farinograph.

3.15.3 Dough development time

This is the time need to the curve to attain its maximum consistency, possessing highest
peak. High peak values are associated with strong flour, which have long mixing time.

3.15.4 Dough stability
The dough stability was interpreted as the difference between arrival time and departure time.

3.15.5 Mixing tolerance index
The mixing tolerance index (MTI) value was derived in Brabender Unit (BU) as the difference from top of the curve at peak to the top of curve after 5 min. from peak.

3.15.6 Softening of dough
It was determined as the difference in BU from center of curve at peak and center of curve 12 min. after peak.

3.16 Mixographic studies
The wheat flour was run through mixograph to assess mixing properties of the dough i.e. mixing time and peak height percentage, by adopting the method No. 22-10 mentioned in AACC (2000). About 10g of flour sample on the base of 14 % moisture was weighed and taken in the bowl of mixograph. Water was added to the flour sample by using burette after that the bowl was put in into the mixograph. Mixograph results include peak height and peak time.

3.17 Amylographic studies
The viscosity and gelatinization properties of dough were determined by using amylograph according to the procedure described in AACC (2000).

3.18 Preparation of product

3.18.1 Saponin removal
Removal of saponin is consider as necessary part before consumption of quinoa as or in food products. At lab-scale or lower level, removal of saponin was done by washing the quinoa seed with tab water (Mahoney et al., 1975).

3.18.2 Preparation of bread
The breads was prepared from straight grade flour containing quinoa flour at level of 0%, 5%, 10%, 15% and 20% by the method according to the procedure developed by AACC (2000) in the bakery of NIFSAT, University of Agriculture, Faisalabad-Pakistan. For the dough preparation, all the ingredients were added in the mixer and mixed for 5 minutes and after that placed in fermenter which is preset at 75% relative humidity and 30°C for 180 minutes. After about 120 and 150 minutes of fermentation, first and second punches were
made respectively. The dough was given a rounded shape with weight of 100g and put in test pans so that final proofing was done at 35°C and 85 % relative humidity for 45 mintues. Baking of panned dough was carried out for 25 minutes at 230°C.

3.19 Product analyses

3.19.1 Bread texture analyses

Bread analysis was for texture was carried by using texture analyzer according to the methods described by Philips and Falcone (1988):

3.19.2 Cyclic compression test

For the determination of compression test of bread, the cyclic compression procedure was adopted, in which samples were compressed twice for about 50%. Under stress, recovery behavior and deformation showed gumminess and firmness of bread.

3.19.3 Penetration test

Penetration test was performed in order to check the bread fractueability by following the method No. 74-09 (AACC, 2000). Cylindrical ball die were used to pentrates the slices of bread up to 40%.

3.19.4 Sensory evaluation of bread

The sensory evaluation of breads was carried out by trained panel of 9 judges to witness the impact of quinoa flour addition on bread quality by following the method described by Matz (1960) Evaluations of all bread were carried out under white florescent light at room temperature. On day of evaluation, the whole bread along with the slice of each bread prepared from addition of different level of quinoa flour were placed in trays, each bread were coded with random codes. Bread treatments were provided in random order to panelists and were requested to assign their liking by giving a score for different external (Volume, Color of Crust, Symmetry of Form, Evenness of Bake, Character of Crust as well as Break and Shred) as well as internal characteristics (Grain, Color of Crumb, Aroma, Taste, Mastication or Chewability and Texture) by following the Performa developed by American Institute of Baking and adopted by Matz (1960), in which they further divided the bread characteristics into internal and external characteristics with subtotal 30 and 70 respectively, Anexure-I(Bread Evaluation Performa). The detailed explanation of each characteristic has been mentioned in Annexure II.

3.20 In-vivo protein analysis

The availability and digestibility of the protein in the quinoa protein isolate were
determined by using the method of Matthews et al. (2011) with some modification.

3.20.1 Diet composition
Composition of diet was established by following the recommendations as discussed by Reeves et al. (1993), with some modifications to fix about 10% protein content of diet and the prepared diets were mixed homogeneously with the help of mixer. The protein contents of diet were determined by the Kjeldahl method (AOAC, 2006). In plastic bags the prepared animal diets were taken and labelled properly, moreover for further utilization feed was stored at 5°C in a refrigerator.

3.20.2 Animals
Efficacy trials involving male Sprague Dawley rats was conducted in the Animal Room of the National Institute of Food Science & Technology, University of Agriculture, Faisalabad-Pakistan. Purposely, 30 male rats were procured, randomly divided into six groups of five animals each. Experimental animals were kept in cages made of stainless steel and room temperature were retained at 22±3°C with a 12 h dark/light cycle. Furthermore, constituted animal groups were fed with diet having no protein or protein deficient, casein and quinoa protein based experimental diets adopting the method of Moraes et al. (2012) with slight modifications.

3.20.3 Feed efficiency ratio (FER)
Feed efficiency ratio was determined using data obtained from feed consumption and body weight gain. For the purpose, animals were weighed on daily basis to investigate feed efficiency ratio (FER) based on rise in weight (g) and intake of diet by the selected experimental rats (g).

3.20.4 Body weight gain
Likewise, body weight gain was also calculated as an indirect indicator of growth index based on the consumption pattern of respective protein diets (Seena et al., 2006).

3.20.5 Protein efficiency ratio and net protein ratio
Protein efficiency ratio (PER) was also calculated by considering rise in body weight of rats with the intake of protein (g) following the method of Sarwar (1997). Moreover, net protein ratio (NPR) was determined by following the protocol of Bender and Doell (1957), by considering body weight gain (W) and weight loss in protein-free diet group (WL) in relation to the test group’s protein consumption pattern (PC) as

\[ \text{Net protein ratio (NPR)} = \frac{W(g) + WL(g)}{PC(g)} \times 100 \]
3.20.6 Nitrogen balance study
Likewise, nitrogen balance study was also performed to analyze nitrogen content to calculate true digestibility (TD), biological value (BV) and net protein utilization (NPU) as described by the methods of Bender and Doell (1957).

3.21 Statistical analysis
The data obtained for each parameter was subjected to analyze under complete randomized design (CRD) to determine the level of significance using Minitab 16, as described by Steel et al. (1997).
CHAPTER 4

RESULTS AND DISCUSSION

The main purpose of present study is to characterize quinoa grown in Pakistan for chemical composition, minerals and trace element profile, fatty acid profile, thermal and pasting properties, and In-vitro digestion of quinoa starch and protein. Furthermore, quinoa protein isolates were extracted & evaluated for their functional properties whilst the effect of quinoa flour substitution on dough rheology and bread quality were also investigated. Bread prepared with the addition of quinoa flour were assessed for different textural & sensorial attributes. Biological evaluation of quinoa protein was assessed by growth parameter i.e. PER (protein efficiency ratio), NPR (net protein ratio) and RNPR relative net protein ratio and nitrogen balance study i.e. TD (true digestibility), BV (biological value) and NPU (net protein utilization) using Sprague Dawley rats. The studied parameters and their outcomes have been discussed below:

4.1 Physical parameters of quinoa

4.1.1 Thousand grain weight

The analysis of variance for thousand grain weight of different quinoa lines have been presented in Table 4.1 showed that thousand grain weight was highly significant among different quinoa lines. The mean values regarding grain weight of quinoa lines have been presented in Table 4.2. Thousand grain weight of *C. quinoa* V7, *C. quinoa* V2, *C. quinoa* V9 and *C. quinoa* V1 lines were found to be 3.78±0.02, 3.21±0.03, 2.08±0.05 and 2.94±0.02g respectively. Highest value of grain weight was found in *C. quinoa* V7 (3.78±0.02g) and the lowest values was found in *C. quinoa* V9 (2.94±0.02g). Values with different lettering depicted significant difference in varieties regarding grain weight and values with same lettering showed non-significant difference. The results obtained in the current research are according to the finding of Vilche *et al.* (2003) who explicated that the thousand grain weight ranged from 2.53 to 3.11g. Miranda *et al.* (2012a) has also reported that quinoa thousand grain weight ranged from 3.00±0.05 to 4.72±0.08g among different quinoa genotypes cultivated in three distinctive geographical zones of Chile. It has been reported that thousand grain weight variation might be due to grain size (Roy *et al.*, 2014).

4.2 Chemical composition of quinoa

Quality characteristics of the quinoa are determined by different parameters *i.e.* moisture content, crude fat, crude protein, crude ash and crude fiber etc. All parameters directly or indirectly were investigated for different features and the results are discussed as under:
Table 4.1 Analysis of variance for thousand grain weight of quinoa seeds

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Thousand grain weight</td>
</tr>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>1.4938**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>0.0029</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.2 Mean values for thousands grain weight of quinoa seed (g)

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Thousand grain weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. quinoa V7</td>
<td>3.78±0.02a</td>
</tr>
<tr>
<td>C. quinoa V2</td>
<td>3.21±0.03b</td>
</tr>
<tr>
<td>C. quinoa V1</td>
<td>2.08±0.05d</td>
</tr>
<tr>
<td>C. quinoa V9</td>
<td>2.94±0.02c</td>
</tr>
</tbody>
</table>

Means having similar letter in column are statistically non-significant (P>0.05)
4.2.1 Moisture content

The mean squares for moisture content of quinoa flour have been shown in Table 4.3. It is revealed from the data that moisture content of quinoa lines varied significantly. The mean values have been presented in Table 4.4 and from the results it is noticed that moisture content in *C. quinoa* V7, *C. quinoa* V2, *C. quinoa* V1 and *C. quinoa* V9 lines were found to be 10.03±0.06, 10.62±0.24, 10.00±0.12 and 9.74±0.22%, respectively. Highest value for moisture content was found in *C. quinoa* V2 (10.62±0.24%) and the lowest in *C. quinoa* V9 (9.74±0.22%). It has been reported that the variation in moisture content of seed might be due to environmental conditions and genetic variability of crops. The data obtained from present study have similar finding suggested by Stikic *et al.* (2012) where it was reported that quinoa have moisture content about 10.87±0.02%. The presented results are duly supported by the finding of Miranda *et al.* (2012b) who elaborated that moisture ranged from 7.77±0.05 to 15.17±0.02% among different genotype of quinoa. Miranda *et al.* (2013) found that quinoa seed moisture content collected from different region showed significant differences ranged from 6.56 to 12.26%. Ando *et al.* (2002) also investigated that the moisture content in quinoa ranged from 10.0 to 11.9%.

4.2.2 Crude ash

The crude ash differed highly significantly among different quinoa lines (Table 4.3). The mean values regarding the crude ash of quinoa lines have been presented in Table 4.4, it is observable that the quinoa lines vary in crude ash. Crude ash of *C. quinoa* V7, *C. quinoa* V2, *C. quinoa* V1 and *C. quinoa* V9 lines were 2.80±0.02, 2.18±0.08, 2.25±0.01 and 2.54±0.04%, respectively. The highest ash content was found in *C. quinoa* V7 (2.80±0.02%) and the lowest in *C. quinoa* V2 (2.18±0.08%). The results of the present study are closely related to the findings of Wright *et al.* (2002b) where it was reported that quinoa have 2.6 to 3.2% of crude ash. Repo-Carrasco-Valencia *et al.* (2010b) also reported that crude ash in quinoa ranged from 2.27±0.10 to 2.93±0.05%. It was observed that variation in crude ash is due to several factors such as genetic variations, soil type, and the use of synthetic fertilizers (Zielinski and Kozlowska, 2000; Miranda *et al.*, 2009).

4.2.3 Crude protein

The analysis of variance for protein content for different quinoa flour indicated that protein content are highly significantly differed (Table 4.3). The mean values regarding the protein content of quinoa varieties have been presented in Table 4.4. Protein contents of
Table 4.3 Means squares for quinoa flour composition (%) 

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Moisture</th>
<th>Ash</th>
<th>Protein</th>
<th>Fat</th>
<th>Crude Fiber</th>
<th>Total Starch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>0.41198*</td>
<td>0.24866**</td>
<td>13.0813**</td>
<td>12.1833**</td>
<td>1.75455**</td>
<td>68.1309**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>0.09227</td>
<td>0.00621</td>
<td>0.1786</td>
<td>0.0689</td>
<td>0.04703</td>
<td>1.5961</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.4 Means for quinoa flour composition (%) 

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Moisture</th>
<th>Ash</th>
<th>Protein</th>
<th>Fat</th>
<th>Fiber</th>
<th>Total starch</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. quinoa V7</td>
<td>10.03±0.06ab</td>
<td>2.80±0.02a</td>
<td>16.08±0.02a</td>
<td>6.50±0.19b</td>
<td>3.52±0.18a</td>
<td>53.43±0.23b</td>
</tr>
<tr>
<td>C. quinoa V2</td>
<td>10.62±0.24a</td>
<td>2.18±0.08c</td>
<td>13.67±0.14b</td>
<td>7.97±0.12a</td>
<td>2.12±0.06b</td>
<td>61.27±0.90a</td>
</tr>
<tr>
<td>C. quinoa V1</td>
<td>10.00±0.12ab</td>
<td>2.25±0.01c</td>
<td>11.00±0.34c</td>
<td>4.32±0.18c</td>
<td>3.19±0.12a</td>
<td>63.15±0.92a</td>
</tr>
<tr>
<td>C. quinoa V9</td>
<td>9.74±0.22b</td>
<td>2.54±0.04b</td>
<td>13.13±0.32b</td>
<td>3.57±0.11d</td>
<td>1.99±0.12b</td>
<td>54.83±0.65b</td>
</tr>
</tbody>
</table>

Means sharing similar letters are statistically non-significant (P>0.05)
C. quinoa V7, C quinoa V2, C quinoa V1 and C. quinoa V9 were 16.08±0.02, 13.67±0.14, 11.00±0.34 and 13.13±0.32%, respectively. Maximum value of crude protein was found in C. quinoa V7 which was 16.08±0.02% and minimum value in C. quinoa V1 which was 11.00±0.34%. The results obtained from the present research work is comparable with findings of Villa et al. (2014) who stated protein content (11.7±0.2%) present in quinoa. The results are in consistent to the findings of Nascimento et al. (2014) who reported that quinoa have 12.10±0.3% of protein. Vega-Galvez et al. (2010) investigated that protein content in quinoa ranged 12.5 to 16.7%. The variation in protein content of seed might be due to soil fertility, application of fertilizers and availability of nitrogen to the plant.

4.2.4 Crude fat

The statistical data regarding fat content of quinoa lines revealed that crude fat of quinoa were highly significantly differed (Table 4.3). The mean values regarding the crude fat of different quinoa have been presented in Table 4.4. From the results, it is indicated that the crude fat of C. quinoa V7, C. quinoa V2, C. quinoa V1 and C. quinoa V9 were 6.50±0.19, 7.97±0.12, 4.32±0.18 and 3.57±0.11, respectively. The highest value of fat was found in C. quinoa V2 which was 7.97±0.12 and lowest value in C. quinoa V9 which was 3.57±0.11. The results presented in this study are supported by the Repo-Carrasco-Valencia et al. (2010b) who investigated that crude fat ranged from 3.95±0.03 to 6.85±0.10%. Current findings are also inline to the findings of Alvarez-Jubete et al. (2009) who indicated that 5.2±0.1% of crude fat were present in quinoa. It have been reported that the variation in fat content of seed might be due to environmental factors like rain fall and genetic variability along with genetic factors of crop (Ovando-Medina et al., 2011).

4.2.5 Crude fiber

The mean squares revealed that crude fiber differed highly significantly among different quinoa lines (Table 4.3). The mean values regarding the crude fiber of quinoa have been presented in Table 4.4. It can be seen that the crude fiber of C. quinoa V7, C. quinoa V2, C. quinoa V1 and C. quinoa V9 were found to be 3.52±0.18, 2.12±0.06, 3.19±0.12 and 1.99±0.12, respectively. Maximum value of crude fiber was found in C. quinoa V7 which was 3.52±0.18% and minimum value in C. quinoa V9 which was 1.99±0.12%. Findings of current study are in line to the finding of Repo-Carrasco-Valencia et al. (2010a) where it was reported that crude fiber in quinoa samples ranged from 1.81±0.02 to 7.04±0.03%. Soliz-Guerrero et al. (2002) described that quinoa have crude fiber about 3.4%. Valencia-
Chamorro (2003) also reported that quinoa have 2.5-3.9% of crude fiber. It has been reported that the high variation for the chemical composition of the seed may be due to genotypes environment and their interactions (Golkar et al., 2011).

4.2.6 Total starch content
The statistical results regarding total starch contents of quinoa depicted that total starch content varied highly significantly among different quinoa (Table 4.3). The mean values regarding the total starch contents of quinoa lines have been presented in Table 4.4. From the results, it is observed that the quinoa lines varied in contents of total starch content. The highest content of total starch was found in *C. quinoa* V1 whilst the lowest amount was found in *C. quinoa* V7 which were 63.15±0.92 and 53.43±0.23%, respectively. Other quinoa lines possessed 61.27±0.90 and 54.83±0.65% in *C. quinoa* V2 and *C. quinoa* V9. It was obvious from the mean table that *C. quinoa* V9 and *C. quinoa* V7 showed non-significant difference regarding total amount of starch. Similarly, *C. quinoa* V2 and *C. quinoa* V1 showed non-significant difference regarding total amount of starch. The present results are matched with the findings of Wright et al. (2002a) who reported that quinoa have 69.2% of starch. Demin et al. (2013) also investigated that quinoa have 59.18±0.02% of total starch. Gerrano et al. (2014) found that total starch content of seed influenced by the genetic variability and environmental conditions.

4.3 Mineral composition of quinoa
The statistical results regarding mineral content of different quinoa lines have been presented in Table 4.5 and Table 4.7. The statistical results indicated that mineral contents in quinoa lines have shown significant variation among different quinoa lines. Moreover, the results regarding the mean values of mineral content in different quinoa varieties have been showed in Table 4.6 and Table 4.8. It is noticeable from the present findings that the different quinoa showed variation in mineral contents *i.e.* aluminum, boron, calcium, copper, iron, potassium, magnesium, manganese, sodium, phosphorus, sulphur and contents of zinc. These differences may be associated to a number of factors like maturity of seed, variety of crop, types of soil, usage of composts, exposure time and intensity of sunlight, temperature and rain (Zielinski and Kozlowska, 2000; Miranda et al., 2009). Ortiz-Monasterio et al. (2007) suggested that mineral content of different crops can be increased through breeding and genetic variations.

4.3.1 Sodium (Na) content
The statistical data regarding sodium content have been presented in Table 4.7. From the
results, it is explicated that there is highly significant difference among quinoa lines. The mean values of sodium have been presented in Table 4.8. The results pertaining to sodium, highest value was found in the *quinoa* V7 and lowest in *C. quinoa* V9 which were 62.81±0.52 and 24.58±0.29 mg/kg respectively. *C. quinoa* V2 and *C. quinoa* V1 have 54.18±0.52 and 51.45±0.26 mg/kg respectively. The present research is correlated with the findings of Ahamed *et al.* (1998) who observe that quinoa have sodium in the range of 27 to 220 mg/kg.

### 4.3.2 Potassium (K) content

The results regarding the mean squares of potassium are presented in Table 4.5. Furthermore, the means values are presented in Table 4.6 which indicated that maximum concentration of potassium was found in *C. quinoa* V9 (9443.41±114.7 mg/kg) and the lowest in *C. quinoa* V1 (8497.08±51.97 mg/kg). While *C. quinoa* V2 has 8920.79±35.06 mg/kg and *C. quinoa* V7 has 8650.63±28.82 mg/kg. Our results are in line with the earlier findings of Ogungbenle (2003) who reported that quinoa has 714.0 mg/kg of potassium. The average value of potassium was 8861.311 mg/kg in different varieties of quinoa. These findings are very close to the Prado *et al.* (2014) who reported that quinoa have 9,520 mg/kg of potassium.

### 4.3.3 Calcium (Ca) content

The statistical analysis for calcium content in quinoa revealed that the calcium content differed highly significantly among different lines (Table 4.5). The mean values of calcium was observed that highest value of calcium 669.45±5.20 mg/kg was found in *C. quinoa* V7 and lowest was recorded in *C. quinoa* V1 which was 578.35±4.53 mg/kg, while *C. quinoa* V2 possessed 598.56±5.83 mg/kg and 621.13±6.37 mg/kg in *C. quinoa* V9 (Table 4.6). Our investigations are in line with the previous findings of Gonzalez Martin *et al.* (2014) who found that the calcium content of different genotype of quinoa ranged 627.9±84.8 to 937.7±308.3 mg/kg. Moreover, these results are in line with the finding of Hager *et al.* (2012b) who determined 497.3±1.2 mg/kg of calcium content in quinoa. Likewise our findings are in close agreement with the results of Ogungbenle (2003) who reported that quinoa flour have 860 mg/kg of calcium. Miranda *et al.* (2010) observed the calcium content in quinoa flour which was from 565.10 mg/kg which is similar to the results obtained from present study.

### 4.3.4 Magnesium (Mg) content

The statistical data regarding magnesium content indicated that there is significant
difference among different lines of quinoa (Table 4.7). The means table regarding the magnesium content are shown in Table 4.8, results depicted that highest value of magnesium was found in C. quinoa V2 and C. quinoa V7 which was 2173.4±23.12 and 2163.2±34.61mgkg⁻¹ while lowest content was found in C. quinoa V9 followed by C. quinoa V1 which were 2058.1±28.28mgkg⁻¹ and 2068.1±28.88mgkg⁻¹ respectively. The findings of recent study are also very close to the results of Ahamed et al. (1998) who found that magnesium content in different varieties of quinoa ranged from 1610 to 26200mgkg⁻¹. Miranda et al. (2010) who found that magnesium content in the quinoa 1760.2mgkg⁻¹. The results of current study was found very close to the findings of Gonzalez Martin et al. (2014) who found magnesium content in quinoa 1839.0±67.8 to 1912.1±213.0 mgkg⁻¹.

4.3.5 Zinc content

The results regarding mean squares of zinc indicated that there is highly significant differences among different lines of quinoa (Table 4.7). However, the mean values (Table 4.8) indicated that highest value was found in C. quinoa V7 and lowest in C. quinoa V9 which was 32.12±0.52 and 24.30±0.22mgkg⁻¹, respectively followed by C. quinoa V2 (29.40±0.25mgkg⁻¹) and C. quinoa V1 (29.15±0.52 mg/kg). The data presented in this study are similar with the findings of Ruales and Nair (1993) who reported that quinoa has 36 mg/kg of zinc. The result of current findings are close to the findings of Karyotis et al. (2003) who reported that quinoa have zinc in the range of 34 to 42 mg/kg. The current results are also very close to the findings of Konishi et al. (2004) who reported that quinoa have 40 mg/kg of zinc.

4.3.6 Iron (Fe) content

The analysis of variance for iron content has been presented in Table 4.5 which indicated that there is highly significant difference among different quinoa lines. The results for means values for iron content are presented in Table 4.6 which indicated that highest concentration was found in C. quinoa V2 about 68.89±0.50 mg/kg and lowest concentration was found in C. quinoa V7 which was 61.31±0.18 mg/kg while C. quinoa V9 possess 64.55±0.29 and C. quinoa V1 have 63.13±0.55 mg/kg. The results of present findings are alike with the findings of Hager et al. (2012b) who found 53.5±0.4 mg/kg of iron content of quinoa. The results presented in this study are supported by the findings of Prado et al. (2014) who reported that quinoa have iron in the range of 47.56 to 98.44mg/kg. The findings of recent study are in conformity with the previous results of Alvarez-Jubete et al. (2010a) also reported that quinoa have 55 mg/kg of iron contents.
Table 4.5  Analysis of variance for quinoa minerals (Al, B, Ca, Cu, Fe and K)

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Al</td>
</tr>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>9.70507**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>0.07000</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.6 Means for minerals (Al, B, Ca, Cu, Fe and K) of quinoa (mg/kg)

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Al</th>
<th>B</th>
<th>Ca</th>
<th>Cu</th>
<th>Fe</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. quinoa</em> V7</td>
<td>16.48±0.09b</td>
<td>15.72±0.21b</td>
<td>669.45±5.20a</td>
<td>4.73±0.03b</td>
<td>61.31±0.18c</td>
<td>8650.63±28.82bc</td>
</tr>
<tr>
<td><em>C. quinoa</em> V2</td>
<td>20.27±0.25a</td>
<td>17.04±0.07a</td>
<td>598.56±5.83bc</td>
<td>5.04±0.06a</td>
<td>68.89±0.50a</td>
<td>8920.79±35.06b</td>
</tr>
<tr>
<td><em>C. quinoa</em> V1</td>
<td>19.80±0.15a</td>
<td>16.63±0.19a</td>
<td>578.35±4.53c</td>
<td>4.01±0.02c</td>
<td>63.13±0.55bc</td>
<td>8497.08±51.97c</td>
</tr>
<tr>
<td><em>C. quinoa</em> V9</td>
<td>20.09±0.05a</td>
<td>15.29±0.05b</td>
<td>621.13±6.37b</td>
<td>4.19±0.05c</td>
<td>64.55±0.29b</td>
<td>9443.41±114.7a</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)
4.3.7 Copper (Cu) content
The means square of copper for different quinoa showed that there is highly significant difference among different lines which are presented in Table 4.5. Means value of different quinoa lines are presented in Table 4.6 which indicated that maximum concentration of copper was found in C. quinoa V2 which was 5.04±0.06 mg/kg and lowest in C. quinoa V1 which was 4.01±0.02, while other such as C. quinoa V7 and C. quinoa V9 have 4.73±0.03 and 4.19±0.05, respectively. The results of our data is accordance with the work of Miranda et al. (2010) who reported that quinoa have copper contents about 2.0 mg/kg. Prado et al. (2014) also found similar findings that quinoa have 4.81 to 11.19 mg/kg in different varieties. The findings of present study are in line with Karyotis et al. (2003) who also found that quinoa have 12.4 to 18.6 mg/kg of copper.

4.3.8 Sulphur (S) content
The mean squares for sulphur content are presented in Table 4.7. It is observable from the result that there is significantly differences among different lines of quinoa in the manner of sulphur. However; the mean values (Table 4.8), indicated that highest value of sulphur was found in C. quinoa V2 and lowest was in C. quinoa V1 which was 1606.30±8.29 and 1499.21±9.30mg/kg, respectively. Other possessed 1582.37±5.84 and 1508.58±4.58 mg/kg in C. quinoa V9 and C. quinoa V7. The findings of current study are similar with results of Konishi et al. (2004) who reported that quinoa has 1500 to 2200 mg/kg of sulphur.

4.3.9 Phosphorus (P) content
The analysis of variance (ANOVA) regarding phosphorus have been presented in Table 4.7 which showed that there is non-significant differences among different lines. Furthermore, different lines i.e. C. quinoa V7, C. quinoa V2, C. quinoa V1, C. quinoa V9 depicted phosphorus as 4500.6±28.93, 4542.6±23.03, 4491.6±20.78 and 4560.0±16.16 mg/kg, respectively. The results of current study are akin to the findings of Bhargava et al. (2006) who found that quinoa contained 3869 mg/kg of phosphorus. The recent findings are also in line with the results of Konishi et al. (2004) who also found that quinoa has 4110 mg/kg. These results are close to the findings of Miranda et al. (2010) who reported that phosphorus (4688.7 mg/kg ) is present in quinoa. The results of the present study are also similar with the previous findings of Prado et al. (2014) who reported that quinoa has 4,120 mg/kg of phosphorus.
Table 4.7 Analysis of variance for minerals of quinoa (Mg, Mn, Na, P, S and Zn)

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mg</th>
<th>Mn</th>
<th>Na</th>
<th>P</th>
<th>S</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>11164.3*</td>
<td>12.9973**</td>
<td>817.353**</td>
<td>3238.74NS</td>
<td>8509.28**</td>
<td>31.7939**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>2524.6</td>
<td>0.1381</td>
<td>0.519</td>
<td>1545.13</td>
<td>157.75</td>
<td>0.4880</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.8 Means for minerals of quinoa flour (Mg, Mn, Na, P, S and Zn) mg/kg

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Mg</th>
<th>Mn</th>
<th>Na</th>
<th>P</th>
<th>S</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. quinoa</em> V7</td>
<td>2163.2±34.61a</td>
<td>35.28±0.12a</td>
<td>62.81±0.52a</td>
<td>4500.6±28.93a</td>
<td>1508.58±4.58ab</td>
<td>32.12±0.52a</td>
</tr>
<tr>
<td><em>C. quinoa</em> V2</td>
<td>2173.4±23.12a</td>
<td>33.49±0.24b</td>
<td>54.18±0.52b</td>
<td>4542.6±23.03a</td>
<td>1606.30±8.29a</td>
<td>29.40±0.25b</td>
</tr>
<tr>
<td><em>C. quinoa</em> V1</td>
<td>2068.1±28.88b</td>
<td>30.66±0.21c</td>
<td>51.45±0.26c</td>
<td>4491.6±20.78a</td>
<td>1499.21±9.30b</td>
<td>29.15±0.52b</td>
</tr>
<tr>
<td><em>C. quinoa</em> V9</td>
<td>2058.1±28.28b</td>
<td>31.46±0.27c</td>
<td>24.58±0.29d</td>
<td>4560.0±16.16a</td>
<td>1582.37±5.84a</td>
<td>24.30±0.22c</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)
4.3.10 Manganese (Mn) content
Mean squares in Table 4.7 for manganese indicated that there is highly significant difference among different lines of quinoa. Moreover, the means (Table 4.8) indicated that maximum concentration of manganese was found in *C. quinoa* V7 which was 35.28±0.12 mg/kg and lowest 30.66±0.21 mg/kg was found in *C. quinoa* V1. While others *C. quinoa* V2 and *C. quinoa* V9 possess 33.49±0.24 mg/kg and 31.46±0.27 mg/kg in respectively. The recent indicated that the findings of present study are in line with the previous results of Ranhotra *et al.* (1993) and Oshodi *et al.* (1999) who found that quinoa flour have 35 mg/kg of manganese. Miranda *et al.* (2010) also found that quinoa have 2.29±0.14 mg/100g (22.9 mg/kg). The findings of current parameter are also similar to the results of Prado *et al.* (2014) who reported that quinoa have 33 mg/kg of manganese content.

4.3.11 Boron (B) content
The statistical results for boron content in quinoa flour of different lines have been presented in Table 4.5. However, means values as shown in Table 4.6 the maximum concentration of boron was found in *C. quinoa* V2 and minimum was found in *C. quinoa* V9 which was 17.04±0.07 and 15.29±0.05 mg/kg, respectively. Furthermore, other lines possess 15.72±0.21 mg/kg and 16.63±0.19 mg/kg in *C. quinoa* V7 and *C. quinoa* V1 respectively. The results of current parameters are close to the findings of Karyotis *et al.* (2003) who reported that quinoa have 39.00 mg/kg of boron.

4.3.12 Aluminum (Al) content
The aluminum content was varied highly significant in different quinoa lines (Table 4.5). The aluminum content ranged from 16.48±0.09 to 20.27±0.25 mg/kg (Table 4.6). Similarly, the highest concentration of aluminum was found in *C. quinoa* V2 and lowest in *C. quinoa* V7 which was 20.27±0.25 mg/kg and 16.48±0.09 mg/kg, respectively. Other quinoa lines such as *C. quinoa* V9 and *C. quinoa* V1 possessed 20.09±0.05 mg/kg and 19.80±0.15 mg/kg, respectively.

4.4 Fatty acid profile of quinoa oil
The means squares of quinoa fatty acid profile are presented in Table 4.9 which representing that there was highly significant variations in fatty acid profile among these quinoa lines. These differences are attributed to the reported differences in environmental conditions during the seed development, genetic makeup, maturity, and agricultural practices (Miranda *et al.*, 2012). The mean values regarding the fatty acid profile of quinoa varieties have been presented in Table 4.10. From the results it is understandable that the
quinoa lines varied in contents of fatty acids like palmitic acid, oleic acid, linoleic acid, α-linolenic acid and erucic acid.

4.4.1 Palmitic acid

Methyl Palmitate (palmitic acid, C16:0), also called as palmitic acid, is saturated fatty acid found in different lines of quinoa. The analysis of variance for palmitic acid have been given in Table 4.9. It is evident from the statistical results that differences in quinoa lines regarding palmitic acid were found to be highly significant. Mean values regarding palmitic acid have been illustrated in Table 4.10 that the highest value was found in *C. quinoa* V9 and lowest in *C. quinoa* V1 which were 13.25±0.30 and 11.39±0.02%, respectively. Other quinoa lines such as *C. quinoa* V2 and *C. quinoa* V7 possessed 12.06±0.06 and 11.76±0.18%, respectively. The data acquired from present study have similar finding suggested by Ando *et al.* (2002) where it was reported that 10.3±0.2% of palmitic acid present in milled grain of quinoa. Hager *et al.* (2012a) illustrated that among saturated fatty acids only palmitic acid was present in abundance in the quinoa. Miranda *et al.* (2012a) reported that palmitic acid was only one saturated fatty acid which is present in abundant amount in different type of quinoa genotypes. The results presented in this study are supported by the findings of Peiretti *et al.* (2013) where it was determined that quinoa has palmitic acid in the range of 114.7 to 129.4 g/kg (11.47 to 12.94%) at maturity stage (115.3 g/kg) (11.53%) was recorded.

4.4.2 Oleic acid

Methyl oleate (Oleic acid), is omega-9 monounsaturated fatty acid. The statistical data regarding oleic acid indicated that oleic acid differed highly significantly among different quinoa lines (Table 4.9). In case of oleic acid, the means values presented in Table 4.10 which indicated that the highest value was found in *C. quinoa* V1 and lowest in *C. quinoa* V2 which were 31.62±0.14 and 26.28±0.15%, respectively. While *C. quinoa* V7 and *C. quinoa* V9 possessed 29.73±0.03 and 28.44±0.29%, respectively. The results of current study are supported by the finding of Ruales and Nair (1993) who exploited that 24.8 g/100g of oleic acid is present in raw whole quinoa. Palombini *et al.* (2013) observed oil of different quinoa varieties for oleic acid content and reported that 20.84 % of oleic acid in quinoa. These results are close related to the findings of Miranda *et al.* (2012b) where it was reported that different quinoa genotypes have oleic acids in the range of 18.68±0.27 to 27.87±0.02 g/100g
4.4.3 Linoleic acid

The mean squares for linoleic acid elucidated that linoleic acid was differed highly significantly among quinoa lines (Table 4.9). Linoleic acid (Methyl Linoleate, C18:2), Linoleic acid (omega-6) polyunsaturated, 18-carbon chain carboxylic acid containing two cis double bonds; first double bond situated at the sixth carbon from the methyl end. Means of Linoleic acid (Table 4.10) indicated that the highest value was found in *C. quinoa* V7 and the lowest in *C. quinoa* V1 which were 52.02±0.54 and 47.79±0.19%, respectively whilst *C. quinoa* V2 and *C. quinoa* V9 possessed 52.84±0.28 and 51.15±0.62%, respectively. Result of current study are in relation to the findings of Ruales and Nair (1993) who elucidated that linoleic acid (52.3 g/100g) is found in different quinoa varieties. Rosero et al. (2013) explored that linoleic acid was most abundantly polyunsaturated fatty acid present in different varieties of quinoa which varied from 46.525 to 56.435 g/100g. These results of present study are also confirmed by the findings of Calderelli et al. (2010) who explicated that quinoa have 48.8±0.41 % of linoleic acid

4.4.4 α-Linolenic Acid

Methyl alpha linolenate (α-linolenic acid) is an essential omega-3 fatty acid having 18-carbon chain and possessing three cis double bonds. Statistical results for α-linolenic acid highly significantly differed among different quinoa lines (Table 4.9). The means for α-linolenic acid presented in Table 4.10. In case of α-linolenic acid highest value was found in *C. quinoa* V7 and lowest in *C. quinoa* V2 which were 7.71±0.06 and 4.45±0.03%, respectively. Other quinoa lines i.e. *C. quinoa* V1 and *C. quinoa* V9 comprised of 7.64±0.11% and 5.58±0.03% α-linolenic acid in quinoa flour. The findings of present study are alike with the finding of Valcarcel-Yamani and Lannes (2012) who reported that values of α-linolenic acids ranged from 3.8 % to 8.3 % in quinoa. Rosero et al. (2013) investigated that quinoa has α-linolenic acid in the range of 6.721 to 8.814 g/100g. Wood et al. (1993) also reported that quinoa have 7.66±0.13 to 8.35±0.07% of α-linolenic acid among different varieties. The quantity of α-linolenic acid were investigated in three quinoa lines which was reported much greater than the 3.9% stated by Ruales and Nair (1993).

4.4.5 Erucic acid

Methyl erucate (Erucic acid) is omega-9 monounsaturated fatty acid. Mean squares regarding erucic acid has been presented in Table 4.9. It is apparent from the result that erucic acid varied highly significantly among quinoa lines.
### Table 4.9 Analysis of variance for quinoa fatty acids

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Palmitic Acid</th>
<th>Oleic Acid</th>
<th>Linoleic Acid</th>
<th>α-Linolenic Acid</th>
<th>Erucic Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>1.94445**</td>
<td>15.0813**</td>
<td>14.7392**</td>
<td>7.69490**</td>
<td>0.05369**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>0.09508</td>
<td>0.0937</td>
<td>0.5904</td>
<td>0.01275</td>
<td>0.00202</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>11</td>
<td><strong>NS</strong></td>
<td><strong>NS</strong></td>
<td><strong>NS</strong></td>
<td><strong>NS</strong></td>
<td><strong>NS</strong></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

### Table 4.10 Means for quinoa fatty acids (%)

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Palmitic Acid</th>
<th>Oleic Acid</th>
<th>Linoleic Acid</th>
<th>α-Linolenic Acid</th>
<th>Erucic Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. quinoa V7</td>
<td>12.06±0.06b</td>
<td>29.73±0.03b</td>
<td>52.02±0.54a</td>
<td>7.71±0.06a</td>
<td>1.41±0.01c</td>
</tr>
<tr>
<td>C. quinoa V2</td>
<td>11.76±0.18b</td>
<td>26.28±0.15d</td>
<td>52.84±0.28a</td>
<td>4.45±0.03c</td>
<td>1.74±0.00a</td>
</tr>
<tr>
<td>C. quinoa V1</td>
<td>11.39±0.02b</td>
<td>31.62±0.14a</td>
<td>47.79±0.19b</td>
<td>7.64±0.11a</td>
<td>1.56±0.05b</td>
</tr>
<tr>
<td>C. quinoa V9</td>
<td>13.25±0.30a</td>
<td>28.44±0.29c</td>
<td>51.15±0.62a</td>
<td>5.58±0.03b</td>
<td>1.58±0.02b</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)
The means presented in Table 4.10 indicated that the highest value of erucic acid was found in *C. quinoa* V2 (1.74±0.00) and while the lowest in *C. quinoa* V7 (1.41±0.01%). Moreover *C. quinoa* V1 and *C. quinoa* V9 contained 1.56±0.05 and 1.58±0.02% respectively. The results with respect to erucic acid in the current study are in corroboration with the earlier work of Wood *et al.* (1993) who reported that erucic acid ranged from 1.87±0.02 to 1.93±0.02% among different quinoa varieties. These findings are further supported by the previous research of Tang *et al.* (2015) who concluded that the erucic acid varied from 1.03±0.01 to 1.09±0.03% among three different varieties of quinoa.

### 4.5 Functional properties of quinoa protein isolates

#### 4.5.1 Water absorption capacity

The analysis of variance (ANOVA) for water absorption capacity have been presented in Table 4.11. It is clear from the results that highly significant variation in water absorption capacity of protein isolate among different quinoa lines. The mean values regarding the water absorption capacity of protein isolate have been presented in Table 4.12. It is apparent from the results that the quinoa protein isolates have highest water absorption capacity in *C. quinoa* V7 which was found to be 3.82±0.05% and lowest was *C. quinoa* V1 which was 2.81±0.17%. The findings of the current research is similar to the results of the Chauhan *et al.* (1999) who found that the water holding capacity of quinoa protein isolate was 5.4±0.2g/g. The water absorption capacity basically calculated on the basis of amount and level of hydration of proteins insoluble fractions. In contrast, protein superior solubility represent less water absorption capacity due to presence of lower contents of insoluble protein fraction.

#### 4.5.2 Oil absorption capacity

Statistical analysis presented in Table 4.11 showed highly significant variations in oil absorption capacity of quinoa protein isolates. The mean values of oil absorption capacity (Table 4.12) depicted that *C. quinoa* V2 contained highest oil absorption capacity (3.03±0.03%) whereas *C. quinoa* V1 has lowest oil absorption capacity (2.72±0.02%). The variation with in different quinoa lines may be due to differences in globular structure and particle size of protein. The present results are in relation with the findings of Chandi and Sogi (2007) who elucidated that the oil absorption capacity of casein and rice protein isolate was found to be 1.72 ± 0.09 % and 6.74 ± 0.34%, respectively.

#### 4.5.3 Emulsion capacity

Mean squares for quinoa protein isolates differed significantly among different quinoa lines.
Table 4.11 Analysis of variance for functional properties of protein isolates

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Water Absorption Capacity (%)</td>
</tr>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>0.68653**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>0.02712</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

* = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.12 Means for functional properties of protein isolates

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Water Absorption Capacity (%)</th>
<th>Oil Absorption Capacity (%)</th>
<th>Emulsion Capacity (%)</th>
<th>Foaming Capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. quinoa V7</td>
<td>3.82±0.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.87±0.05&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>106.53±1.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.05±0.07&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. quinoa V2</td>
<td>3.43±0.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.03±0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>103.64±0.79&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>8.60±0.01&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. quinoa V1</td>
<td>2.81±0.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.72±0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>102.00±0.71&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.74±0.09&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. quinoa V9</td>
<td>3.81±0.04&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.86±0.05&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>102.10±0.63&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.09±0.05&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)
(Table 4.11) whilst the mean values have been presented in Table 4.12. It is evident from the data that the emulsion capacity ranged from 102.00±0.71 to 106.53±1.33%. Maximum emulsion capacity was found in *C. quinoa* V7 and the lowest was found in *C. quinoa* V1. Moreover, other lines *i.e.* *C. quinoa* V2 and *C. quinoa* V9 contained 103.64±0.79 and 102.10±0.63%. The higher emulsifying capacity of quinoa seed protein isolate useful for food applications.

4.5.4 Foaming capacity

The mean squares for foaming capacity of quinoa protein isolates have been shown in Table 4.11. It is revealed from data that foaming capacity of quinoa protein isolates varied significantly among different quinoa lines. The mean values regarding the foaming capacity of quinoa protein isolates have been presented in Table 4.12. It is apparent from the results that the quinoa protein isolates varied in foaming capacity. The quinoa lines such as *C. quinoa* V7, *C. quinoa* V2, *C. quinoa* V1 and *C. quinoa* V9 lines were 10.05±0.07, 8.60±0.01, 7.74±0.09 and 9.09±0.05%, respectively. The highest value of foaming capacity was found in *C. quinoa* V7 which was 10.05±0.07% and the lowest (9.09±0.05%) in *C. quinoa* V9. The results are in line with the findings of Aluko and Monu (2003), who determined that protein isolates of quinoa have low foaming capacity, which might be due to the structure of (globular nature) of the protein.

4.6 In-vitro digestion of quinoa protein

The statistical data regarding pH of mixture (sample & enzymes solution) at time 0 (T0) have been presented in Table 4.13. From data that it is observable the pH at T0 was found to be non-significant among different quinoa lines. Mean values for pH of mixture at time “0” presented in Table 4.14, depicted that the pH at time 0 ranged from 7.85±0.01 to 7.89±0.02, maximum value was found in *C. quinoa* V2 (7.89±0.02) and the lowest value was found in *C. quinoa* V1 (7.85±0.01) while *C. quinoa* V1 and *C. quinoa* V7 have 7.87±0.01 and 7.88±0.01 pH values, respectively. Mean squares regarding pH of mixture at time (t) have been presented in Table 4.13. It is observed from the study that the pH at time “t” was significantly differed among each other. Mean values for pH of mixture at time “t” has been presented in Table 4.14. Results depicted that the pH at time “t” ranged from 0.60±0.01 to 0.45±0.01 for *C. quinoa* V7 and *C. quinoa* V9, respectively, whereas *C. quinoa* V2 and *C. quinoa* V1 have 0.58±0.01 and 0.51±0.01pH, respectively. Mean values with same lettering depicted non-significant difference regarding pH of mixture.
### Table 4.13 Analysis of variance for *In-vitro* protein digestion

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>pH Time (0)</th>
<th>pH Time (t)</th>
<th>pH Time (∞)</th>
<th>Kinetic Rate K=10^3</th>
<th>IVPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>0.000782^NS</td>
<td>0.01299**</td>
<td>0.00867**</td>
<td>3888.92**</td>
<td>2.52864^*</td>
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<tr>
<td>Error</td>
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<td>0.000515</td>
<td>0.00029</td>
<td>0.00097</td>
<td>360.97</td>
<td>0.48071</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

### Table 4.14 Means for *In-vitro* protein digestion (IVPD)

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>pH Time (0)</th>
<th>pH Time (t)</th>
<th>pH Time (∞)</th>
<th>Kinetic Rate K=10^3</th>
<th>IVPD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. quinoa</em> V7</td>
<td>7.87±0.01^a</td>
<td>0.60±0.01^c</td>
<td>7.28±0.03^c</td>
<td>274.13±5.070^bc</td>
<td>78.11±0.43^a</td>
</tr>
<tr>
<td><em>C. quinoa</em> V2</td>
<td>7.89±0.02^a</td>
<td>0.58±0.01^c</td>
<td>7.31±0.01^bc</td>
<td>288.36±11.16^ab</td>
<td>76.74±0.57^ab</td>
</tr>
<tr>
<td><em>C. quinoa</em> V1</td>
<td>7.88±0.01^a</td>
<td>0.51±0.01^b</td>
<td>7.37±0.02^ab</td>
<td>238.50±7.300^c</td>
<td>76.52±0.21^ab</td>
</tr>
<tr>
<td><em>C. quinoa</em> V9</td>
<td>7.85±0.01^a</td>
<td>0.45±0.01^a</td>
<td>7.40±0.02^a</td>
<td>325.53±16.67^a</td>
<td>75.95±0.29^b</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)
The statistical analysis regarding pH of mixture at time infinity have been shown in Table 4.13. It is evident from the findings that the pH at infinity was significantly differed among different quinoa lines. Mean values for pH of mixture at infinity have been presented in Table 4.14. Result showed that the pH at infinity varied from 7.28±0.03 to 7.40±0.02 for C. quinoa V7 and C. quinoa V9, respectively whilst C. quinoa V2 and C. quinoa V1 have 7.31±0.01 and 7.37±0.02, respectively. Mean values with same lettering depicted non-significant variation regarding pH of digested material. The means squares regarding kinetic rate of protein digestion have been presented in Table 4.13. It is portrayed from the results that significant difference was found among different quinoa lines. The mean values regarding digestion rate presented in Table 4.14 showed that maximum digestion rate was observed in C. quinoa V9 (325.53±16.67min⁻¹) and the lowest (238.50±7.30min⁻¹) was found in C. quinoa V1 whereas C. quinoa V7 and C. quinoa V2 contained 274.13±5.070 and 288.36±11.16/min, respectively. Means having similar lettering are statistically non-significant. These variation for digestion rate among different quinoa lines might be due to the globular size of protein and presence of other limiting factors.

The statistical data regarding in-vitro digestion of quinoa protein showed significant differences among quinoa lines (Table 4.13). The mean values for in-vitro protein digestibility has been presented in Table 4.14 which elucidated that quinoa lines have significant differences for the said parameter. The in-vitro protein digestibility of C. quinoa V7, C. quinoa V2, C. quinoa V1 and C. quinoa V9 were found to be 78.11±0.43, 76.74±0.57, 76.52±0.21 and 75.95±0.29%, respectively. The highest value of in-vitro protein digestibility was found in C. quinoa V7 which was 78.11±0.43% and the lowest in C. quinoa V9 (75.95±0.29%). The findings of the current study are in line with the previous study of Repo-Carrasco-Valencia and Serna (2011) who observed that the in-vitro protein digestibility of quinoa varied between 76.3-80.5% among different varieties.

4.7 Gelatinization properties quinoa

Gelatinization is breaking down of intermolecular structural bond between starch molecule in the presence of heat and water which allowed bonding site to absorb more water (Jenkins and Donald, 1998). Swelling of starch granules start from the onset temperature (T_o) in differential canning calorimetry endothermic transition. Differential scanning calorimetry (Dürrenberger et al.) endothermic is used to investigate melting and glass transition temperatures along with changes in heat flow of polymeric elements and provides confirmation on arrangement portents of starch granules (Biliaderis et al., 1986).
The mean squares regarding the gelation properties of quinoa have been presented in Table 4.15. It is clear from the results that the quinoa varied significantly for gelation properties which comprised of different parameters i.e. onset temperature ($T_o$), peak temperature ($T_p$), end temperature ($T_e$), change in energy per gram of solid and change in energy per gram of starch. These properties are used to express the overall gelation behavior of flour. Wani et al. (2012) demonstrated that differential scanning calorimetry parameters like $T_o$, $T_p$, $T_e$, and $\Delta H_g$ are effected by the starch molecular structure in crystalline region, which relates to the scattering of short-chain amylopectin and not by the quantity of the crystalline region which relates to the content of amylose.

In case of onset temperature ($T_o$), mean values (Table 4.16) indicating that the highest value was found in $C. quinoa$ V7 and the lowest in $C. quinoa$ V1 which were 62.78±0.10°C and 53.90±0.24°C, respectively whilst $C. quinoa$ V2 and $C. quinoa$ V9 possessed 59.74±0.04°C and 55.02±2.39°C, respectively.

Regarding the peak temperature, the statistical data indicated that there is significant difference among different quinoa lines. The mean values regarding peak temperature (Table 4.16) depicted that the highest value was found in $C. quinoa$ V7 and lowest in $C. quinoa$ V9 which were 74.61±0.06°C and 60.75±0.59°C, respectively. Other quinoa lines i.e. $C. quinoa$ V2 and $C. quinoa$ V9 have 65.51±0.24°C and 61.00±0.68°C, respectively.

As for as end temperature is concerned, from the result it is observable that the end temperature significantly varied among different quinoa lines. The means of end temperature indicated that the highest value was found in $C. quinoa$ V7 and lowest was in $C. quinoa$ V1 which were 74.61±0.06°C and 64.82±0.19°C, respectively. Moreover, other two lines i.e. $C. quinoa$ V2 and $C. quinoa$ V9 possess 71.58±0.17°C and 66.41±1.21°C values respectively.

Statistical data regarding enthalpy of different quinoa lines have been elucidated in Table 4.15. It is indicated from the study that the enthalpy differed significantly among all quinoa lines. The means for the enthalpy presented in Table 4.16 indicated that, highest value was found in $C. quinoa$ V7 (7.11±0.24 Jg$^{-1}$) and lowest in $C. quinoa$ V9 (3.03±0.19Jg$^{-1}$). While other lines such as $C. quinoa$ V2 and $C. quinoa$ V1 have 3.55±0.27 and 4.31±0.33, respectively.
Table 4.15 Mean Squares for gelatinization properties quinoa flour and starch

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Onset Temp ($T_0$) $^\circ$C</th>
<th>Peak Temp $^\circ$C</th>
<th>End Temp ($T_e$) $^\circ$C</th>
<th>$\Delta H$ J g$^{-1}$ (solids)</th>
<th>$\Delta H$ J g$^{-1}$ (dry starch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>51.4011**</td>
<td>39.9451**</td>
<td>61.8084**</td>
<td>9.94143**</td>
<td>30.8287**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>4.3303</td>
<td>0.6466</td>
<td>1.1468</td>
<td>0.21002</td>
<td>0.6696</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.16 Means for gelatinization properties of quinoa flour and starch

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Onset Temp ($T_0$) $^\circ$C</th>
<th>Peak Temp $^\circ$C</th>
<th>End Temp ($T_e$) $^\circ$C</th>
<th>$\Delta H$ J g$^{-1}$ (solids)</th>
<th>$\Delta H$ J g$^{-1}$ (dry starch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. quinoa V7</td>
<td>62.78±0.10$^a$</td>
<td>68.26±0.03$^a$</td>
<td>74.61±0.06$^a$</td>
<td>7.11±0.24$^a$</td>
<td>12.97±0.44$^a$</td>
</tr>
<tr>
<td>C. quinoa V2</td>
<td>59.74±0.04$^{ab}$</td>
<td>65.51±0.24$^b$</td>
<td>71.58±0.17$^b$</td>
<td>3.55±0.27$^{bc}$</td>
<td>5.79±0.44$^b$</td>
</tr>
<tr>
<td>C. quinoa V1</td>
<td>53.90±0.24$^c$</td>
<td>61.00±0.68$^c$</td>
<td>64.82±0.19$^c$</td>
<td>4.31±0.33$^b$</td>
<td>6.83±0.53$^b$</td>
</tr>
<tr>
<td>C. quinoa V9</td>
<td>55.02±2.39$^{bc}$</td>
<td>60.75±0.59$^c$</td>
<td>66.41±1.21$^c$</td>
<td>3.03±0.19$^c$</td>
<td>7.58±0.47$^b$</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)
As for enthalpy of quinoa starch is concerned significant difference among lines (Table 4.15) has been observed. The mean values for enthalpy of quinoa starch presented in Table 4.16 indicted that highest temperature was found in *C. quinoa* V7 (12.97±0.44 Jg⁻¹) and lowest in *C. quinoa* V9 (5.79±0.44 Jg⁻¹). In other lines mean values sharing similar letters are statistically non-significant. The result of current study are very close to the finding of Steffolani *et al.* (2013) where they found that onset temperature varied from 54.25 to 55.72°C and peak temperature ranged from 61.66 to 63.01°C. The variation in the temperature might be due to presence of protein and lipase content (Yamin *et al.*, 1999) as well as chain length of amylopectin (Jane *et al.*, 1999). Gelatinization Enthalpy showed the complete measurement of molecular architecture of crystalline region and its quantity as well as the loss of molecular order in the granules of starch. Gelation enthalpy (ΔH) ranged from 5.8±1.1 to 13.0±1.1 J/g. Results of current study for quinoa starch enthalpy are much closed to the results of Ando *et al.* (2002) where they reported that enthalpy of quinoa starch was 11.0±0.5 J/g. These variation in the ranges of gelatinization temperature might be due to the existence of short branch chains of amylopectin (Jane *et al.*, 1999). Moreover, gelatinization characters determined by DSC can be effected by other factors than presence of the amount of amyllose. It has been reported that ratio of short chain amylopectin negatively correlated to the onset temperature as well as peak temperature (Noda *et al.*, 1998; Noda *et al.*, 2003; Vandeputte *et al.*, 2003).

### 4.8 In-vitro digestion of quinoa starch

The statistical data regarding *in-vitro* digestion of quinoa starch has been presented in Table 4.17. It is depicted from the results that the digestion at time “0” of different quinoa significantly differed among quinoa lines which indicated that the digestion of quinoa starch start when the process started. The digestion at time “0” ranged from 5.21±0.07 to 8.98±0.49 (Table 4.18). It is depicted from the data that highest digestion of quinoa starch at time “0” was found in *C. quinoa* V9 and lowest was found in *C. quinoa* V2. While other have 8.70±0.28 and 8.75±0.02 for *C. quinoa* V7 and *C. quinoa* V1, respectively. Analysis of variance (ANOVA) depicted that the digestion at time “t” of different quinoa significantly differed among each other and ranged from 70.42±1.14 to 83.23±1.77 (Table 4.18). It is noticeable from the results that highest digestion of quinoa starch at time “t” was found in *C. quinoa* V2 and lowest value was found in *C. quinoa* V9 while *C. quinoa* V7 and *C. quinoa* V1 contained 82.59±1.01 and 81.96±1.41, respectively.

The speed and degree of starch digestion starch is related to the release of reducing sugar
during digestion process and hence the glycemic response. It have been reported that
the interaction between protein and starch in food matrix effect the digestibility and glycemic
index response to starch (Brennan and Samyue, 2004).
Mean squares for digestion at time infinity indicating (Table 4.17) that quinoa lines are
non-significantly differed among each other. Mean values of digested starch at infinite time
interval has been presented in Table 4.18. It is apparent that the quinoa varieties didn’t vary
in contents of digested starch at infinitive time interval. Digested starch at infinitive time
interval for C. quinoa V7, C. quinoa V2, C. quinoa V1, and C. quinoa V9 were found to
be 91.29±0.67, 88.44±2.05, 90.70±1.44 and 79.41±0.55, respectively. The highest value of
digested starch at infinitive time interval was found in C. quinoa V7 which was 91.29±0.67
and lowest in C. quinoa V9 which was 79.41±0.55.
Mean squares for digestion rate per minute of different quinoa starch indicated that
digestion rate significantly differed in quinoa lines. Mean values of digestion rate per
minute has been presented in Table 4.18. It is depicted from the data that the quinoa starch
digestion rate per minute for quinoa lines i.e. C. quinoa V7, C. quinoa V2, C. quinoa V1,
C. quinoa V9 were found to be 19.97±0.503, 21.34±9.109, 17.42±1.543 and 23.88±1.806,
respectively. The highest value for digestion rate was found in C. quinoa V9 which was
23.88±1.04 and the lowest value in C. quinoa V1 which was 17.42±0.89. Benmoussa et al.
(2006) investigated that pronounced starch-protein interactions in an envelope of protein
and this delays admittance by amylolytic enzymes. Furthermore, intact cell walls may also
act as an encapsulating barrier that can create hinder in digestion rate of starch. The starch
digestibility might be affected by the development of complexes between lipid and
amylose, protein and starch interactions, the occurrence of anti-nutritional factors like
amylose inhibitors, processing techniques and modification of starch structure (Eyaru et al.,
2009; Wong et al., 2009; Putseys et al., 2010; Barrett and Udani, 2011).
Enzymatic digestion of starch can be affected by many factors such as granule size, non-
starch components, crystalline pattern, amyllose to amylopectin ratio, presence of
lipids, presence of minerals, presence of proteins, digestion conditions and milling
conditions (Benmoussa et al., 2007; Vieira and Sarmento, 2008). Starch digestion rate
varied among different types of food, and it is effected by inherent nature of digesting
material like cell walls of material and depend on the time required to transit material in
the gastro-intestinal tract. Starch digestibility might also depends on its intrinsic structure,
crystallinity, physical encapsulation, degree of
Table 4.17 Analysis of variance for *In-vitro* starch digestion

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Digestion Time (0)</th>
<th>Digestion Time (t)</th>
<th>Digestion Time (∞)</th>
<th>Digestion rate Kx10⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>9.76123**</td>
<td>111.937**</td>
<td>91.0200NS</td>
<td>21.8359**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>0.23991</td>
<td>5.575</td>
<td>5.2714</td>
<td>2.3854</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.18 Means for *In-vitro* starch digestion

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Digestion Time (0)</th>
<th>Digestion Time (t)</th>
<th>Digestion Time (∞)</th>
<th>Digestion rate Kx10⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. quinoa V7</em></td>
<td>8.70±0.28ᵃ</td>
<td>82.59±1.01ᵃ</td>
<td>91.29±0.67ᵃ</td>
<td>19.97±0.64ᵃᵇ</td>
</tr>
<tr>
<td><em>C. quinoa V2</em></td>
<td>5.21±0.07ᵇ</td>
<td>83.23±1.77ᵃ</td>
<td>88.44±2.05ᵃ</td>
<td>21.34±0.95ᵃᵇ</td>
</tr>
<tr>
<td><em>C. quinoa V1</em></td>
<td>8.75±0.02ᵃ</td>
<td>81.96±1.41ᵃ</td>
<td>90.70±1.44ᵃ</td>
<td>17.42±0.89ᵇ</td>
</tr>
<tr>
<td><em>C. quinoa V9</em></td>
<td>8.98±0.49ᵃ</td>
<td>70.42±1.14ᵇ</td>
<td>79.41±0.55ᵇ</td>
<td>23.88±1.04ᵃ</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)
gelatinization, retrogradation and proportion of damaged granules. Tharanathan and Mahadevamma (2003) also documented the low digestibility of legume starch recognized due to its amylase because of high molecular weight and branching.

4.9 Pasting properties quinoa flour

4.9.1 Rapid visco analyzer (RVA)

Pasting character of starch is due to amylase content, granule shape, granule distribution, granule-granule interaction (Sajilata et al., 2006). Starch has specific viscosity that changes with change in temperature, concentration, and shear rate.

4.9.2 Setback viscosity

Setback viscosity is the re-association or re-arranging between molecules of starch during cooling process. It involves retro-gradation, or re-arranging, of the molecules, and has been associated with texture of numerous products. The ANOVA regarding setback viscosity of different quinoa lines have been shown in Table 4.21. The results explicated that trough viscosity showed highly significant differences among different quinoa lines. The mean values for setback viscosity (Table 4.22) indicated that the setback viscosity of different quinoa line ranged from 346.0±30.51 to 113.3±04.67RVU. The highest value was found in C. quinoa V9 while lowest in C. quinoa V2. The findings of present study are correlated with the results of Steffolani et al. (2013) who found that the setback viscosity of different quinoa verities ranged from 67 to 963cp. Belton and Taylor (2002) observed that setback viscosity varied from 20 to 370 among different treatments of quinoa flours but who found maximum setback viscosity of raw quinoa seed flour. The high setback might be due to these starches which might possess shorter chain amylase than the other starches.

4.9.3 Peak time

It is observable from the statistical results that peak time was found to be non-significant among different quinoa lines (Table 4.21). The mean values regarding the peak time have been presented in Table 4.22. It is evident from the results that peak time for C. quinoa V7, C. quinoa V2, C. quinoa V1 and C. quinoa V9 was found to be 6.98±0.02, 6.98±0.01, 6.97±0.02 and 6.99±0.01min, respectively. Values with same lettering depicted non-significant difference in varieties regarding peak time. Alvarez-Jubete et al. (2010a) found
### Table 4.19 Analysis of variance for pasting properties of quinoa flour

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Peak Viscosity</th>
<th>Trough Viscosity</th>
<th>Break Down Viscosity</th>
<th>Final Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>10761.6*</td>
<td>5690.5*</td>
<td>941.63*</td>
<td>40979.6**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>1674.9</td>
<td>1034.4</td>
<td>135.25</td>
<td>2585.7</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* = Significant (P<0.05); ** = Highly significant (P<0.01)

### Table 4.20 Means for pasting properties of quinoa flour

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Peak Viscosity (RVU)</th>
<th>Trough Viscosity (RVU)</th>
<th>Break Down Viscosity (RVU)</th>
<th>Final Viscosity (RVU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. quinoa V7</td>
<td>374.3±12.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>301.7±5.81&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.67±6.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>530.0±15.87&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. quinoa V2</td>
<td>232.0±11.37&lt;sup&gt;b&lt;/sup&gt;</td>
<td>198.0±9.54&lt;sup&gt;b&lt;/sup&gt;</td>
<td>34.00±2.52&lt;sup&gt;b&lt;/sup&gt;</td>
<td>311.3±10.40&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. quinoa V1</td>
<td>272.7±34.69&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>230.0±31.21&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>42.67±3.48&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>476.7±31.47&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. quinoa V9</td>
<td>297.0±27.43&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>234.7±16.74&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>62.33±10.97&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>580.7±45.80&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)
that peak time of different pseudo-cereal amaranth, quinoa and buckwheat ranged from 5.7 to 6.4min which is similar to the current findings of the research. The finding of Lindeboom et al. (2005b) and Steffolani et al. (2013) also support to the results of the current study. Where they found that the peak time 5.1 to 6.9min and 4.97 to 5.17min respectively.

4.9.4 Pasting temperature

The temperature higher than the gelatinization, starch granules instigate to swell, is termed as pasting temperature. Viscosity tends to increase as a result of shear forces produced by the swollen granules. So pasting temperature is defined as the temperature at which rise in viscosity starts.

The statistical data regarding peak temperature (Table 4.21) indicated that there is highly significant difference among the pasting temperature of different quinoa lines. The highest pasting temperature was found in C. quinoa V9 which is 74.28±0.96°C whilst the lowest (62.18±1.02°C) was found in C. quinoa V1 (Table 4.22). The pasting temperature of C. quinoa V7 and C. quinoa V2 have been reported as 68.37±2.17 and 67.82±1.95°C, respectively. The data acquired from present study are close to the finding by Qian and Kuhn (1999) who reported that pasting temperature of pseudo cereals such as quinoa and amaranth ranged from 66.8 to 71.7°C, respectively. Lindeboom et al. (2005a) found that the pasting temperature of quinoa ranged from 63.0 to 64.0°C which was found to be significantly different among different quinoa seeds in pasting characteristics.

4.9.5 Peak viscosity

Peak viscosity defined as the maximum viscosity developed during or immediately after the heating phase of the test. The analysis of variance regarding peak viscosity revealed that the peak viscosity significantly affected by quinoa lines (Table 4.19). The mean values regarding the peak viscosity have been presented in Table 4.20. It is apparent from the results that the highest value for peak viscosity found in C. quinoa V7 whilst lowest was found in C. quinoa V2 which was 374.3±12.17RVU and 232.0±11.37RVU, respectively. Moreover, peak viscosity for C. quinoa V1 and C. quinoa V9 was 272.7±34.69 and 297.0±27.43RVU, respectively which was statistically non-significant among each other. The outcomes of current study are significantly correlated with the finding of Alvarez-Jubete et al. (2010a) who found that peak viscosity ranged from 273 to 341.4RVU among different pseudo-cereals amaranth, quinoa and buck wheat. Qian and Kuhn (1999) found the peak viscosity in pseudo-cereal i.e. amaranth and quinoa 138.5 to 345.9RVU, respectively. Belton and Taylor (2002) found that the peak viscosity of quinoa flour ranged
### Table 4.21 Analysis of variance for pasting properties of quinoa flour

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Setback Viscosity</td>
</tr>
<tr>
<td>Quinoa Lines</td>
<td>3</td>
<td>27296.3**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>1462.5</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

### Table 4.22 Means for pasting properties of quinoa flour

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>Setback Viscosity (RVU)</th>
<th>Peak Time (min.)</th>
<th>Pasting Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. quinoa V7</td>
<td>228.3±10.09^b</td>
<td>6.98±0.02^a</td>
<td>68.37±2.17^ab</td>
</tr>
<tr>
<td>C. quinoa V2</td>
<td>113.3±04.67^c</td>
<td>6.98±0.01^a</td>
<td>67.82±1.95^ab</td>
</tr>
<tr>
<td>C. quinoa V1</td>
<td>246.7±29.92^ab</td>
<td>6.97±0.02^a</td>
<td>62.18±1.02^b</td>
</tr>
<tr>
<td>C. quinoa V9</td>
<td>346.0±30.51^a</td>
<td>6.99±0.01^a</td>
<td>74.28±0.96^a</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)
from 10 to 318RVU which is significantly varied among different treatments.

4.9.6 Trough viscosity

The mean squares for trough viscosity (Table 4.19) indicated that this parameter varied significantly due to differences in quinoa lines. The trough viscosity (Table 4.20) ranged from 198.0±9.54 to 301.7±5.81 RVU. The highest value of trough viscosity was recorded in *C. quinoa* V7 and the lowest was in *C. quinoa* V2, while other quinoa lines *i.e.* *C. quinoa* V1 and *C. quinoa* V9 possessed 230.0±31.21 and 234.7±16.74 RVU, respectively. The data acquired from present study are akin to the finding of Alvarez-Jubete *et al.* (2010a) who reported that trough viscosity of pseudo-cereal ranged from 225.5 to 293.4 RVU in amaranth and quinoa.

4.9.7 Breakdown viscosity

Difference between peak viscosity and trough viscosity is called breakdown viscosity. The analysis of variance (ANOVA) for breakdown viscosity indicated that there is significant difference among different quinoa lines (Table 4.19). The breakdown viscosity ranged from 34.00±2.52 to 72.67±6.44RVU (Table 4.20). The highest value was found in *C. quinoa* V7 and lowest in *C. quinoa* V2, while *C. quinoa* V1 and *C. quinoa* V9 contained 42.67±3.48 and 62.33±10.97RVU respectively. The findings of present study are significantly correlated with the finding of Steffolani *et al.* (2013) who found that the breakdown viscosity of different quinoa seed flour ranged from 439 to 1161cp (equal to 36.5 to 96.75RVU). Qian and Kuhn (1999) found the breakdown viscosity of amaranth and quinoa ranged from 72.5 to 74.8 RVU, respectively.

4.9.8 Final viscosity

Final viscosity can be defined as the aptitude of a substance to produce a gel or thick paste after cooking and cooling. The mean squares for final viscosity of different quinoa flour have been presented in Table 4.19. It is evident from the result that the final viscosity was highly significant differed among different quinoa lines. The mean values regarding the final viscosity of quinoa varieties have been presented in Table 4.20 It is apparent from the result that the highest value of final viscosity was found in *C. quinoa* V9 (580.7±45.80RVU) and the lowest in *C. quinoa* V2 (311.3±10.40RVU).

The outcomes of current study are close to the finding of finding of Steffolani *et al.* (2013) who found that the final viscosity of different quinoa seed flour ranged from 3725 to 4109 cp which is equal to 310.42 to 342.42 RVU. Qian and Kuhn (1999) found that the final viscosity of pseudo-cereal amaranth and quinoa ranged from 108 to 416.2 RVU
respectively. Moreover, Alvarez-Jubete et al. (2010a) found that the final viscosity of pseudo-cereal i.e. amaranth and quinoa ranged from 191.8 to 321.6RVU respectively.

4.10 Effect of composite flour on rheological properties
Rheology is the discipline of deformation and flow of materials, both solid and liquid, an understanding of its principles is important to study food texture. The rheological characteristics provide information regarding dough handling, behavior, and properties which play a key role in quality of the finished products. The dough rheological properties are influenced by the structure of the aggregates and their tendency to interact with each other. The farinograph, mixograph and amylograph are common equipment used for assessing the rheological properties of dough (Mani et al., 1992).

4.10.1 Farinographic studies
The farinograph is a sensitive instrument which measures the water absorption and mixing behavior of flour during mixing. It provides information about the water required for dough to reach a certain consistency and secondly a general profile of the mixing behavior of dough.

4.10.1.1 Water Absorption
Mean squares regarding the water absorption of composite flour have been presented in Table 4.23. It showed highly significant variation in water absorption due to quinoa lines and relative supplementations from control. The statistical splitting, further depicted that lines caused significant variation and treatments showed highly significant variation, however; their interaction have non-significant effect on water absorption of composite flour.

Mean values for the effects of quinoa flour on water absorption of composite flour (Table 4.24) depicted the increasing trend from $T_0$ to $T_4$. For all lines best treatment is $T_4$, which means that substitution of flour of any quinoa line give best results regarding water absorption at 20 % level as compared to control (Figure 4.1). The mean values of the water absorption for $T_0$, $T_1$, $T_2$, $T_3$ and $T_4$ were $63.22\pm0.046\%$, $64.06\pm0.110\%$, $64.77\pm0.095\%$, $65.32\pm0.120\%$ and $66.00\pm0.123\%$, respectively. The highest water absorption was observed in $T_4$ (20% quinoa flour + 80% wheat flour) and lowest in $T_0$ (control) which was
Table 4.23 Analysis of variance for Water absorption (%)  

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>2.281**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>9.324**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.361*</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>8.145**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.183 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.117</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.24 Means for water absorption of composite flour

<table>
<thead>
<tr>
<th>Treat</th>
<th>Quinoa Lines</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>63.95±0.196</td>
<td>64.43±0.242</td>
</tr>
<tr>
<td>T2</td>
<td>64.78±0.143</td>
<td>65.00±0.283</td>
</tr>
<tr>
<td>T3</td>
<td>65.55±0.244</td>
<td>65.32±0.241</td>
</tr>
<tr>
<td>T4</td>
<td>66.49±0.232</td>
<td>65.79±0.146</td>
</tr>
<tr>
<td>Mean</td>
<td>65.20±0.297^a</td>
<td>65.14±0.179^ab</td>
</tr>
<tr>
<td>T0</td>
<td>Straight grade wheat Flour</td>
<td>63.22±0.046</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100% wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
found to be 66.00±0.123% and 63.221±0.046%, respectively. Regarding the mean values of different quinoa lines, the highest value of water absorption was found in \textit{C. quinoa} V7 and lowest in \textit{C. quinoa} V9 which were 65.20±0.297% and 64.49±0.933% respectively. \textit{C. quinoa} V7 and \textit{C. quinoa} V9 showed significant difference for water absorption while \textit{C. quinoa} V2 and \textit{C. quinoa} V1 showed similar behavior to each other. Among lines \textit{C. quinoa} V7 is best as it gave better results for all treatment then other quinoa lines (Figure 4.1).

The findings from the present study are in accordance with the earlier in which Shahzadi \textit{et al.} (2005) indicated that there was increase in water absorption with an increase in protein contents, samples containing chickpea and lentil absorbed more water due to increase in protein content in composite flour. Other factors like starch damage during milling also affects water absorption. The results are in accordance to the findings of Enriquez \textit{et al.} (2003) in which water absorption ranged from 56.3 to 57.3% and was positively correlated with protein content. It was reported that during mixing proteins are hydrated that may be a factor that affect significantly water absorption and dough consistency (Bonet \textit{et al.}, 2006). This increase in water absorption might be attributed to starch damage which was much higher in the quinoa samples (Chauhan \textit{et al.}, 1992).

4.10.1.2 Dough development time

The mean squares for dough development time (DDT) have been shown in Table 4.25. It is revealed from the data that moisture content of quinoa lines varied significantly. It exposed highly significant difference among all treatments when compared with control. Furthermore, it was observed that variation in dough development time was only due to the treatments while interaction between quinoa lines and treatment was non-significant. It is clear from the results given in Table 4.26 that dough development time in different treatments ranged from 5.66±0.017 to 6.09±0.027min. Significantly the highest dough development time was observed in treatment T4 (6.09±0.027min.) followed by treatment T3 (5.96±0.022min.), T2 (5.88±0.020min.) and T1 (5.66±0.017min.). The lowest dough development time (5.54±0.035min.) was found in T0 (control).

It is also evident from results that the dough development time varied from 5.86±0.046 to 5.93±0.058min among different lines. The highest dough development time was observed in \textit{C. quinoa} V2 (5.93±0.058) followed by \textit{C. quinoa} V9 (5.90±0.046min.) and \textit{C. quinoa} V7 (5.89±0.053min) while minimum dough development time (5.86±0.046min) was observed in \textit{C. quinoa} V1. As lines didn’t affect dough development time so substituting
Table 4.25 Analysis of variance for dough development time (DDT min.)

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.101**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>0.344**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.009 NS</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.389**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.009 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.004</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); ** = Highly significant (P<0.01)

Table 4.26 Means for dough development time (min.) of composite flour

<table>
<thead>
<tr>
<th>Treat</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>C. quinoa V7</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>C. quinoa V2</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>C. quinoa V1</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>C. quinoa V9</em></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>5.62±0.038</td>
<td>5.66±0.017&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>T2</td>
<td>5.86±0.032</td>
<td>5.88±0.020&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>T3</td>
<td>6.02±0.038</td>
<td>5.96±0.022&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>T4</td>
<td>6.05±0.049</td>
<td>6.09±0.027&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Means</td>
<td>5.89±0.053</td>
<td>5.90±0.046</td>
</tr>
<tr>
<td>T0</td>
<td>Straight grade wheat Flour</td>
<td>5.544±0.035</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T<sub>0</sub>= 0% quinoa flour + 100 % wheat flour
T<sub>1</sub>= 5% quinoa flour + 95% wheat flour
T<sub>2</sub>= 10% quinoa flour + 90% wheat flour
T<sub>3</sub>= 15% quinoa flour + 85% wheat flour
T<sub>4</sub>= 20% quinoa flour + 80% wheat flour
Figure 4.1 Effect of composite flour on water absorption (%)

Figure 4.2 Effect of composite flour on dough development time (min.)

$T_0= 0\%$ quinoa flour + $100\%$ wheat flour, $T_1= 5\%$ quinoa flour + $95\%$ wheat flour, $T_2= 10\%$ quinoa flour + $90\%$ wheat flour, $T_3= 15\%$ quinoa flour + $85\%$ wheat flour, $T_4= 20\%$ quinoa flour + $80\%$ wheat flour
any quinoa lines would give similar results (Figure 4.2). Interaction of lines with treatments, all lines showed increasing trend in bread dough development time from T₁ to T₄. The findings of present study are supported by the findings of Chauhan et al. (1992) who stated that dough development time of composite flour increased as the ratio of quinoa flour in composite flour increased.

4.10.1.3 Dough stability

The values regarding the mean squares of dough stability (DS) has been presented in Table 4.27. It is revealed that highly significant difference was observed for dough stability among all treatments in comparing with control. Quinoa lines caused significant variation in dough stability while treatments and interaction of lines and treatments caused highly significant variation in dough stability.

It is evident from the mean results (Table 4.28) that dough stability in different treatments ranged from 5.33±0.054 to 6.30±0.072min. Significantly the highest dough stability (6.30±0.072min) was observed for T₁ followed by T₂ (6.05±0.018min) and T₃ (5.81±0.056min), while lowest dough stability (5.33±0.054min) was found in T₄. It is also evident that the dough stability varied from 5.96±0.083 to 5.80±0.156min among different lines. The highest dough stability (5.96±0.083) was observed in C. quinoa V9 followed by C. quinoa V7 (5.91±0.129min) and C. quinoa V2 (5.83±0.092min) while minimum dough stability was observed in C. quinoa V1 (5.80±0.156min).

As for as interaction of lines with treatments is concerned, all lines showed decreasing trend in dough stability from T₁ to T₄. In 5% substitution C. quinoa V1 showed best results among quinoa lines and at 10 %, 15 % and 20 % substitution C. quinoa V9 depicted better results than other quinoa lines as evident from Figure 4.3. Maximum increase was observed in C. quinoa V7. The findings of current results are very close to the research of Rosell et al. (2009) who described that dough stability in mixing process declined with increasing part of quinoa flour which may be due to dilution in gluten content when flour of wheat replacement with gluten free flour. The studies of Jancurova et al. (2009b) also supported the results of current findings who reported that dough stability revealed a linear reduction with the increasing in the content of pseudo-cereals which might be due to reduction in the resistance index with reverence to the control dough by adding of gluten free flour.
Table 4.27 Analysis of variance for dough stability (DS min.)

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.524**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>1.382**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.067*</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>9</td>
<td>2.040**</td>
</tr>
<tr>
<td>L x T</td>
<td></td>
<td>0.076**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.019</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

* = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.28 Means for dough stability of composite flour

<table>
<thead>
<tr>
<th>Treat</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>6.38±0.283&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.21±0.055&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>T2</td>
<td>6.05±0.032&lt;sup&gt;a-d&lt;/sup&gt;</td>
<td>6.01±0.058&lt;sup&gt;b-e&lt;/sup&gt;</td>
</tr>
<tr>
<td>T3</td>
<td>5.89±0.041&lt;sup&gt;c-f&lt;/sup&gt;</td>
<td>5.67±0.046&lt;sup&gt;d-g&lt;/sup&gt;</td>
</tr>
<tr>
<td>T4</td>
<td>5.34±0.044&lt;sup&gt;gh&lt;/sup&gt;</td>
<td>5.44±0.048&lt;sup&gt;gh&lt;/sup&gt;</td>
</tr>
<tr>
<td>Means</td>
<td>5.91±0.129&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>5.83±0.092&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Straight grade wheat Flour</td>
<td>6.573±0.038</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T<sub>0</sub>= 0% quinoa flour + 100 % wheat flour
T<sub>1</sub>= 5% quinoa flour + 95% wheat flour
T<sub>2</sub>= 10% quinoa flour + 90% wheat flour
T<sub>3</sub>= 15% quinoa flour + 85% wheat flour
T<sub>4</sub>= 20% quinoa flour + 80% wheat flour
4.10.1.4 Mixing tolerance index

Mean squares for mixing tolerance index (MTI) have been presented in (Table 4.29), which revealed a highly significant difference among factors under study and control. Exploring the experimental measures further revealed that lines, treatments, and interaction of lines and treatment caused highly significant variation in mixing tolerance index.

It is apparent from the results given in Table 4.30 that mixing tolerance index in different treatments ranged from 68.47±0.211 to 71.45±0.428. Significantly the highest mixing tolerance index (71.45±0.428) was observed for T4 followed by T3 (70.61±0.270) and T2 (69.69±0.293). The lowest mixing tolerance index (68.47±0.211) was found in T1. Among different quinoa lines, the mixing tolerance index varied from 69.08 to 70.87. The highest mixing tolerance index (70.87±0.511) was observed in C. quinoa V2 followed by C. quinoa V9 (70.14±0.175) and C. quinoa V1 (70.13±0.571) while minimum mixing tolerance index (69.08±0.254) was observed in C. quinoa V7.

As for as interaction of lines with treatments is concerned, all lines showed increasing trend in bread mixing tolerance index from T1 to T4. Maximum increase was observed in C. quinoa V1. Mixing tolerance index of C. quinoa V1 and C. quinoa V7 showed the best at T2, T3 and T4 respectively based on values closer to control as shown in Figure 4.4. The current findings are similar to the findings of Chauhan et al. (1992) who reported that there is increase in mixing tolerance index as increased the level of quinoa in composite flour. It might be due to decrease in gluten content that cause increase in mixing tolerance index.

4.10.1.5 Softening of dough

The values regarding the mean squares for softening of dough has been presented in (Table 4.31), where depicted variation in softening of dough by the quinoa lines and level of flour used. There is highly significant difference among all the treatments. Other treatments also showed highly significant difference as compare to control. The statistical splitting experimental measures further revealed that lines, treatments, and their interaction instigated highly significant variation on softening of dough.

Mean values of softening of dough has been presented in Table 4.32 results showed that softening of dough in different treatments ranged from 98.84±1.191 to 126.58±2.603. Significantly the highest softening of dough (126.58±2.603) was observed for T4 followed by T3 (118.07±2.298) and T2 (107.63±2.189). The lowest softening of dough (98.84±1.191) was found in T1. However, among different lines softening of dough varied from 106.33±2.494 to 121.85±3.460. The highest softening of dough (121.85±3.460) was
### Table 4.29 Analysis of variance for mixing tolerance index (FU)

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>7.867**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>21.691**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>6.483**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>19.507**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>2.913**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.158</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

### Table 4.30 Means for mixing tolerance index of composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>68.11±0.095g</td>
<td>68.11±0.061g</td>
</tr>
<tr>
<td>T2</td>
<td>68.51±0.259ge</td>
<td>71.02±0.050bc</td>
</tr>
<tr>
<td>T3</td>
<td>69.71±0.162df</td>
<td>71.96±0.303ab</td>
</tr>
<tr>
<td>T4</td>
<td>70.00±0.260c-e</td>
<td>72.39±0.263a</td>
</tr>
<tr>
<td>Means</td>
<td>69.08±0.254c</td>
<td>70.87±0.511a</td>
</tr>
<tr>
<td>T0</td>
<td>Straight grade wheat Flour</td>
<td>67.283±0.035</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour  
T1= 5% quinoa flour + 95% wheat flour  
T2= 10% quinoa flour + 90% wheat flour  
T3= 15% quinoa flour + 85% wheat flour  
T4= 20% quinoa flour + 80% wheat flour
Figure 4.3 Effect of composite flour on dough stability (min.)

$T_0 = 0\%$ quinoa flour + $100\%$ wheat flour, $T_1 = 5\%$ quinoa flour + $95\%$ wheat flour, $T_2 = 10\%$ quinoa flour + $90\%$ wheat flour, $T_3 = 15\%$ quinoa flour + $85\%$ wheat flour, $T_4 = 20\%$ quinoa flour + $80\%$ wheat flour

Figure 4.4 Effect of composite flour on mixing tolerance index (MTI)
### Table 4.31 Analysis of variance for softening of dough (FU)

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>570.50**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>1483.29**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>558.98**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>1757.01**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>77.41**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>1.12</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

### Table 4.32 Means for softening of dough (Lines x Treatment interaction)

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T₁</td>
<td>95.15±0.508g</td>
<td>104.09±0.638f</td>
</tr>
<tr>
<td>T₂</td>
<td>103.60±0.341f</td>
<td>120.09±0.957cd</td>
</tr>
<tr>
<td>T₃</td>
<td>121.00±0.602c</td>
<td>129.10±0.550b</td>
</tr>
<tr>
<td>T₄</td>
<td>136.09±0.547a</td>
<td>134.11±1.044a</td>
</tr>
<tr>
<td>Means</td>
<td>113.96±4.773b</td>
<td>121.85±3.460a</td>
</tr>
</tbody>
</table>

| T₀      | Straight grade wheat Flour | 89.857±0.331 |

Means with similar letter are statistically non-significant (P>0.05)

T₀= 0% quinoa flour + 100 % wheat flour
T₁= 5% quinoa flour + 95% wheat flour
T₂= 10% quinoa flour + 90% wheat flour
T₃= 15% quinoa flour + 85% wheat flour
T₄= 20% quinoa flour + 80% wheat flour
Figure 4.5 Effect of composite flour on softening of dough (SOD)

$T_0$ = 0% quinoa flour + 100% wheat flour
$T_1$ = 5% quinoa flour + 95% wheat flour
$T_2$ = 10% quinoa flour + 90% wheat flour
$T_3$ = 15% quinoa flour + 85% wheat flour
$T_4$ = 20% quinoa flour + 80% wheat flour
observed in *C. quinoa* V2 followed by *C. quinoa* V7 (113.96±4.773) and *C. quinoa* V9 (108.97±2.126) while minimum softening of dough (106.33±2.494) was observed in *C. quinoa* V1. The results also showed a significant increase in softening of dough with increasing of quinoa flour in wheat flour. The values of softening of dough of all quinoa lines showed distinctively different values from each other.

The interaction of lines with treatments showed an increasing trend in softening of dough from T1 to T4. At T1, T2, T3 and T4 *C. quinoa* V1, *C. quinoa* V7, *C. quinoa* V9 and *C. quinoa* V1 showed values which are closer to the value of control as observed from Figure 4.5. The maximum increase was observed in *C. quinoa* V7. The results of the present study are in resemblance with the findings of Jančurová et al. (2009b) where it was reported that softening of dough increased as increase in the level of pseudo-cereal in wheat flour. The dough softening associated with demolition of dough and shortening of the gluten fiber along with the suspension of turgid gluten constituent part causing in a lessening of the mastication resistance. The findings of present research also supported by the research of Demin et al. (2013) who reported that softening of dough increase with increase in the level of pseudo-cereal in wheat flour which ranged from 70±0.0 to 227.5±7.5 BU.

**4.10.2 Effect of composite flour on mixographic parameters**

**4.10.2.1 Mixing Time**

Values regarding the mean squares for mixing time has been presented in Table 4.33. It revealed highly significant difference among all treatment combinations. Results further revealed that lines and treatments caused highly significant variation in mixing time while interaction of lines and treatment have non-significant effect on mixing time.

It is noticeable from the results given in Table 4.34 that mixing time in different treatments was found to be ranged from 5.54±0.038 to 6.00±0.024. Significantly the highest mixing time (6.00±0.024 min.) was observed for T1 followed by T2 (5.77±0.030 min.) and T3 (5.72±0.028 min.), while the lowest mixing time (5.54±0.038 min.) was found in treatment T4. All quinoa lines depicted best results at 5% substitution (Figure 4.4). It is also evident from results that the mixing time varied from 5.64±0.060 to 5.86±0.045 among different lines. The highest mixing time (5.86±0.045 min.) was observed in *C. quinoa* V2 followed by *C. quinoa* V1 (5.77±0.048 min.) and *C. quinoa* V7 (5.75±0.058 min.) whilst minimum mixing time in *C. quinoa* V9 (5.64±0.060 min.). A significant increasing trend in mixing time with the increase of quinoa flour in wheat flour was observed. The values of mixing time of all quinoa lines showed distinctively different values from each other and *C. quinoa*
Table 4.33 Analysis of variance table for mixing time (min.)

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.113**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>0.210**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.097**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.423**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.005 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.005</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.34 Means for mixing time of composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>6.02±0.035</td>
<td>6.08±0.049</td>
</tr>
<tr>
<td>T2</td>
<td>5.78±0.032</td>
<td>5.84±0.061</td>
</tr>
<tr>
<td>T3</td>
<td>5.69±0.049</td>
<td>5.81±0.049</td>
</tr>
<tr>
<td>T4</td>
<td>5.50±0.029</td>
<td>5.72±0.026</td>
</tr>
<tr>
<td>Means</td>
<td>5.75±0.058b</td>
<td>5.86±0.045a</td>
</tr>
<tr>
<td>T0</td>
<td>Straight grade wheat Flour</td>
<td>6.483±0.018</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
V2 proved better quinoa line on all concentration because of its value is closer to control (Figure 4.6). As far as interaction of lines with treatments is concerned, all lines showed increasing trend in bread mixing time from T₁ to T₄, while the maximum increase was observed in C. quinoa V7. Dhingra and Jood (2004) also observed a decrease in the mixing time of composite flours due to increase in the level of soya and barley supplementation. Koca and Anil (2007) found that the flaxseed supplementation at 15 and 20% with wheat flour resulted in the weakening of dough and decrease in mixing time. The decrease in mixing time of composite flours might be due to decrease in their gluten contents, coarser nature of quinoa flour particles added to wheat flours and weakening of protein network due to proteolytic activity of composite flours.

4.10.2.2 Peak height

Values regarding the mean squares for peak height (PH) has been presented in (Table 4.35) that revealed highly significant variation caused by concentration of different quinoa flour among all treatments. The statistical splitting further revealed that quinoa lines, treatments, and their interaction caused highly significant variation on peak height.

It is clear from the results given in Table 4.36 that peak height in different treatments ranged from 58.99±0.167 to 63.70±0.139. Significantly the highest peak height (63.70±0.139) was observed for T₁ followed by T₂ (62.07±0.211) and T₃ (60.72±0.335) and the lowest peak height (58.99±0.167) was found in T₄. It is also evident from results that the peak height varied non-significantly from 60.62±0.676 to 61.66±0.503 among different lines. The highest peak height (61.66±0.503) was observed in C. quinoa V1 followed by C. quinoa V9 (61.64±0.516) and C. quinoa V2 (61.55±0.498) while minimum peak height (60.62±0.676) was observed in C. quinoa V7.

The results also showed a significant decreasing trend in peak height with the increase of quinoa flour in wheat flour. The values for peak height of C. quinoa V1 and C. quinoa V9 showed similar values while C. quinoa V2 and C. quinoa V7 showed distinctively different values. As for as interaction of lines with treatments is concerned all lines showed decreasing trend for peak height from T₁ to T₄. At different concentration different lines gave better results being closer results to control such as C. quinoa V7 at T₁, C. quinoa V2 at T₂, C. quinoa V9 at T₃ and C. quinoa V1 at T₄ (Figure 4.7). The maximum decrease was observed in C. quinoa V7. Koca and Anil (2007) demonstrated a decline in the stability of dough with the addition of 15 and 20% flaxseed flour in the wheat flour which is identical to our results. The negative effects on rheological behavior of the composite flours due
Table 4.35 Analysis of variance table for peak height (PH)

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>13.001**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>40.884**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>3.037**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>47.918**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>1.586**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.106</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.36 Means for peak height (Lines x Treatment interaction)

<table>
<thead>
<tr>
<th>Treat.</th>
<th>C. quinoa V7</th>
<th>C. quinoa V2</th>
<th>C. quinoa V1</th>
<th>C. quinoa V9</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>64.07±0.141\textsuperscript{a}</td>
<td>63.49±0.265\textsuperscript{ab}</td>
<td>64.05±0.111\textsuperscript{a}</td>
<td>63.19±0.203\textsuperscript{ab}</td>
</tr>
<tr>
<td>T2</td>
<td>61.04±0.186\textsuperscript{de}</td>
<td>62.68±0.159\textsuperscript{bc}</td>
<td>62.05±0.220\textsuperscript{cd}</td>
<td>62.49±0.264\textsuperscript{bc}</td>
</tr>
<tr>
<td>T3</td>
<td>59.07±0.185\textsuperscript{fg}</td>
<td>60.69±0.152\textsuperscript{e}</td>
<td>61.02±0.185\textsuperscript{e}</td>
<td>62.09±0.207\textsuperscript{c}</td>
</tr>
<tr>
<td>T4</td>
<td>58.29±0.119\textsuperscript{g}</td>
<td>59.36±0.229\textsuperscript{f}</td>
<td>59.52±0.248\textsuperscript{f}</td>
<td>58.80±0.097\textsuperscript{fg}</td>
</tr>
<tr>
<td>Means</td>
<td>60.62±0.676\textsuperscript{b}</td>
<td>61.55±0.498\textsuperscript{a}</td>
<td>61.66±0.503\textsuperscript{a}</td>
<td>61.64±0.516\textsuperscript{a}</td>
</tr>
<tr>
<td>T0</td>
<td>Straight grade wheat Flour</td>
<td>65.173±0.087</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T\textsubscript{0}= 0% quinoa flour + 100% wheat flour
T\textsubscript{1}= 5% quinoa flour + 95% wheat flour
T\textsubscript{2}= 10% quinoa flour + 90% wheat flour
T\textsubscript{3}= 15% quinoa flour + 85% wheat flour
T\textsubscript{4}= 20% quinoa flour + 80% wheat flour

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Figure 4.6 Effect of composite flour on mixing time

Figure 4.7 Effect of composite flour on peak height (PH)

T₀ = 0% quinoa flour + 100% wheat flour, T₁ = 5% quinoa flour + 95% wheat flour, T₂ = 10% quinoa flour + 90% wheat flour, T₃ = 15% quinoa flour + 85% wheat flour, T₄ = 20% quinoa flour + 80% wheat flour

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to increase in the level of quinoa flour might be attributed to weakening of dough due to increase in non-gluten proteins contributed by higher levels of quinoa flour. The high fat content contributed by quinoa flour in composite flours might be another factor that resulted in the decline in peak height of the composite flours.

4.10.3 Effect of composite flour on amylographic properties

4.10.3.1 Peak viscosity

Values regarding the mean squares for peak viscosity (Table 4.37) revealed highly significant effect of quinoa lines and their level of substitution on peak viscosity among all treatments. The statistical splitting further revealed that quinoa lines, treatments, and interaction of lines and treatments caused highly significant effect on peak viscosity.

It is understandable from the results given in Table 4.38 that peak viscosity in different treatments ranged from 1298.7±7.64 to 1416.5±5.89 BU. Significantly the highest peak viscosity (1416.5±5.89BU) was observed in T4 followed by T3 (1387.0±9.32BU) and T2 (1341.6±11.2BU), while the lowest peak viscosity (1298.7±7.64BU) was found in T1. It is also evident from results that the peak viscosity varied from 1334.1±13.13 to 1404.4±12.28 among different lines. The highest peak viscosity (1404.6 BU) was observed in *C. quinoa* V7 followed by *C. quinoa* V1 (1360.0BU) and *C. quinoa* V2 (1345.3BU) while minimum (1334.1BU) in *C. quinoa* V9.

The results also showed a significant increasing trend in peak viscosity with the increase of quinoa flour. The values of peak viscosity for all lines showed distinctively different values from each other. As for as interaction of lines with treatments is concerned all lines showed increasing trend in peak viscosity from T1 to T4. The maximum increase was observed in *C. quinoa* V7 behave better at 5 % concentration substitution however, *C. quinoa* V1 at 10 % substitution, *C. quinoa* V9 at 15 % and 20 % substitution (Figure 4.8).

The findings of current study are supported by Debet and Gidley (2006) who reported that peak viscosity increase as increase in the level of non-wheat source in composite flour, it might be due to lower in gluten content that are associated with a higher peak viscosity it is also indicative for higher swelling of starch.

4.11 Effect of composite flour on chemical composition of bread

4.11.1 Ash content of bread

Values regarding the mean squares of ash has been presented in Table 4.39. It revealed highly significant difference among all treatments. Exploring the experimental measures further revealed that quinoa lines and treatments caused highly significant variation in ash
Table 4.37 Analysis of variance for peak viscosity (BU).

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>10249.6**</td>
</tr>
<tr>
<td>C vs others</td>
<td>1</td>
<td>29759.4**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>11422.1**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>32048.7**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>424.7**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>70.4</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.38 Means for peak viscosity of composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
<td>C. quinoa V1</td>
</tr>
<tr>
<td>T1</td>
<td>1340.5±5.32^g</td>
<td>1290.0±6.11^ha</td>
<td>1283.3±2.50^i</td>
</tr>
<tr>
<td>T2</td>
<td>1401.7±6.64^c</td>
<td>1315.3±5.45^gb</td>
<td>1339.5±5.69^fg</td>
</tr>
<tr>
<td>T3</td>
<td>1430.3±5.17^ab</td>
<td>1370.4±5.76^dc</td>
<td>1397.1±4.04^c</td>
</tr>
<tr>
<td>T4</td>
<td>1445.2±2.30^a</td>
<td>1405.4±5.02^bc</td>
<td>1420.1±4.51^abc</td>
</tr>
<tr>
<td>Means</td>
<td>1404.4±12.28^a</td>
<td>1345.3±13.85^c</td>
<td>1360.0±16.13^b</td>
</tr>
<tr>
<td>T0</td>
<td>Straight grade wheat Flour</td>
<td>1258.4±1.10</td>
<td></td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
Figure 4.8 Effect of composite flour on peak viscosity (PV)

\[ T_0 = 0\% \text{ quinoa flour} + 100\% \text{ wheat flour} \]
\[ T_1 = 5\% \text{ quinoa flour} + 95\% \text{ wheat flour} \]
\[ T_2 = 10\% \text{ quinoa flour} + 90\% \text{ wheat flour} \]
\[ T_3 = 15\% \text{ quinoa flour} + 85\% \text{ wheat flour} \]
\[ T_4 = 20\% \text{ quinoa flour} + 80\% \text{ wheat flour} \]
while interaction of quinoa lines and treatments non-significant effect on bread ash.

It is clear from the results given in Table 4.40 that ash in different treatments ranged from 1.47±0.007 to 1.62±0.017%. Significantly the highest ash content (1.62±0.017%) was observed for treatment T4 followed by treatment T3 (1.57±0.016%) and T2 (1.52±0.007%). The lowest ash content (1.47±0.007%) was found in treatment T1 and it is considered as best with ash contents closer to control (Figure 4.9). It is also evident from results that the ash varied from 1.51±0.015 to 1.59±0.025% among different quinoa lines. The highest ash content (1.59±0.025) was observed in C. quinoa V7 followed by C. quinoa V9 (1.56±0.018%) and C. quinoa V1 (1.52±0.01%) while minimum ash (1.51±0.015%) was observed in C. quinoa V2 and considered as best quinoa line.

The results also showed a significant increasing trend in ash content with the increase of quinoa flour. Interaction of lines with treatments showed increasing trend in bread ash from T1 to T4. Maximum increase was observed in C. quinoa V7. Results of current findings are in line with the findings of Olaoye et al. (2006) where it was reported that ash content of bread increased with the increasing in the level of non-wheat source in the composite flour, ash content of the composite flour bread ranged from 0.64 to 1.17%.

4.11.2 Protein content of bread

The mean squares of protein (Table 4.41) revealed highly significant difference among all treatments when compared with control. Exploring the statistical measures further revealed that quinoa lines, treatments and their interaction showed highly significant variation on crude protein of bread.

Table 4.42 contains the mean values of protein indicating that protein in different treatments ranged from 11.28±0.032 to 11.63±0.107%. Significantly the highest protein was observed for treatment T4 (11.62±0.107%) followed by treatment T3 (11.52±0.083%) and T2 (11.39±0.052%). The lowest protein (11.28±0.032%) was found in treatment T1. It is also evident from results that the protein varied from 11.17±0.018 to 11.77±0.084% among different quinoa lines. The highest protein (11.77±0.084%) was observed in C. quinoa V7 followed by C. quinoa V2 (11.48±0.048%) and C. quinoa V9 (11.41±0.036%) while minimum protein (11.17±0.018%) was observed in C. quinoa V1.

Significant increasing trend in protein with the increase of quinoa flour in wheat flour was observed. The bread protein of all quinoa lines showed different values from each other. As for as interaction of quinoa lines with treatments is concerned all quinoa lines showed increasing trend except C. quinoa V1 in bread protein from T1 to T4. Maximum increase
Table 4.39 Analysis of variance for bread ash prepared from composite flour

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.016**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>0.043**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.016**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.051**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.001 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.001</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); ** = Highly significant (P<0.01)

Table 4.40 Means for bread ash prepared form composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td>1.42±0.006</td>
</tr>
<tr>
<td>T1</td>
<td>1.49±0.015</td>
<td>1.45±0.006</td>
</tr>
<tr>
<td>T2</td>
<td>1.54±0.015</td>
<td>1.49±0.015</td>
</tr>
<tr>
<td>T3</td>
<td>1.63±0.038</td>
<td>1.52±0.003</td>
</tr>
<tr>
<td>T4</td>
<td>1.69±0.012</td>
<td>1.57±0.020</td>
</tr>
<tr>
<td>Means</td>
<td>1.59±0.025&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.51±0.015&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T<sub>0</sub> = 0% quinoa flour + 100 % wheat flour  
T<sub>1</sub> = 5% quinoa flour + 95% wheat flour  
T<sub>2</sub> = 10% quinoa flour + 90% wheat flour  
T<sub>3</sub> = 15% quinoa flour + 85% wheat flour  
T<sub>4</sub> = 20% quinoa flour + 80% wheat flour
Table 4.41 Analysis of variance bread protein prepared from composite flour

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.233**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>0.230**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.745**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.253**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.057**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.005</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.42 Means for bread Protein

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T₁</td>
<td>11.41±0.049&lt;sup&gt;c-f&lt;/sup&gt;</td>
<td>11.30±0.046&lt;sup&gt;c-g&lt;/sup&gt;</td>
</tr>
<tr>
<td>T₂</td>
<td>11.63±0.024&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>11.41±0.050&lt;sup&gt;c-f&lt;/sup&gt;</td>
</tr>
<tr>
<td>T₃</td>
<td>11.92±0.015&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.55±0.065&lt;sup&gt;b-d&lt;/sup&gt;</td>
</tr>
<tr>
<td>T₄</td>
<td>12.13±0.026&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.67±0.052&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Means</td>
<td>11.77±0.084&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.48±0.048&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>T₀</td>
<td>100% Straight grade wheat flour</td>
<td></td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T₀= 0% quinoa flour + 100% wheat flour
T₁= 5% quinoa flour + 95% wheat flour
T₂= 10% quinoa flour + 90% wheat flour
T₃= 15% quinoa flour + 85% wheat flour
T₄= 20% quinoa flour + 80% wheat flour
Figure 4.9 Effect of composite flour on bread crude ash (%)

Figure 4.10 Effect of composite flour on bread Protein (%)

\[ T_0 = 0\% \text{ quinoa flour} + 100\% \text{ wheat flour}, \quad T_1 = 5\% \text{ quinoa flour} + 95\% \text{ wheat flour}, \]
\[ T_2 = 10\% \text{ quinoa flour} + 90\% \text{ wheat flour}, \quad T_3 = 15\% \text{ quinoa flour} + 85\% \text{ wheat flour}, \]
\[ T_4 = 20\% \text{ quinoa flour} + 80\% \text{ wheat flour} \]
was observed in *C. quinoa* V7. *C. quinoa* V1 showed protein value in accordance to control’s as depicted from Figure 4.10. These findings are supported by the previous research of Olaoye et al. (2006) who reported that increase in protein content was observed with progressive increase in amount of flour of soybean in the soybean flour supplemented bread, indicating that supplementation of wheat flour with soy flour would greatly improve the protein content of bread due to that reason it might be due to the higher quantity of protein content in quinoa flour.

4.11.3 Fat content of bread

Values regarding the mean squares of fat has been presented in Table 4.43. It revealed highly significant difference among all treatments when compared to control. The statistical measures further revealed that quinoa lines and interaction of quinoa lines with treatments caused highly significant variation on fat content while treatments showed non-significant variation on bread fat content.

It is clear from the results given in Table 4.44 that fat in different treatments ranged from 5.87±0.105 to 5.92±0.031%. Non-significantly the highest fat (5.92±0.031%) was observed for treatment T1 followed by treatment T2 (5.90±0.061%) and T3 (5.89±0.084%). The lowest fat (5.87±0.105%) was found in treatment T4. It is also evident from results that the fat varied from 5.64±0.039 to 6.22±0.034% among different quinoa lines. The highest fat (6.22±0.034%) was observed in *C. quinoa* V2 followed by *C. quinoa* V7 (6.00±0.015%) and *C. quinoa* V1 (5.73±0.028%) while minimum fat (5.64±0.039%) was observed in *C. quinoa* V9 (Figure 4.11).

As for as interaction of quinoa lines with treatments is concerned all quinoa lines showed decreasing trend in bread fat from T1 to T4 but decreasing trend is statistically non-significant.

4.11.4 Fiber content of bread

Bread fiber varied in experimental measures from control used in the study and can be viewed from Table 4.45. The statistical measures further revealed that quinoa lines, treatments, and interaction of quinoa lines and treatments showed highly significant variation in bread fiber.

It is evident from the results given in Table 4.46 that fiber in different treatments ranged from 1.31±0.014 to 1.52±0.040. Significantly the highest fiber content (1.52±0.040) was observed for treatment T4 followed by treatment T3 (1.45±0.028) and T2 (1.37±0.023). The lowest fiber content (1.31±0.014) was found in treatment T1.
Table 4.43 Analysis of variance for bread fat prepared from composite flour

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.184**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>0.003*</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.840**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.004 NS</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.046**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.002</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.44 Means for bread fat prepared from composite flour (%)

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>5.94±0.015d</td>
<td>6.06±0.032cd</td>
</tr>
<tr>
<td>T2</td>
<td>5.98±0.003de</td>
<td>6.18±0.038bc</td>
</tr>
<tr>
<td>T3</td>
<td>6.03±0.017d</td>
<td>6.27±0.012ab</td>
</tr>
<tr>
<td>T4</td>
<td>6.05±0.027cd</td>
<td>6.35±0.026a</td>
</tr>
<tr>
<td>Means</td>
<td>6.00±0.015b</td>
<td>6.22±0.034a</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td></td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
Table 4.45 Analysis of variance for bread fiber prepared from composite flour

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.049**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>0.096**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.103**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.106**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.007**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.001</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.46 Bread fiber prepared from composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>1.35±0.006e-h</td>
<td>1.28±0.017eh</td>
</tr>
<tr>
<td>T2</td>
<td>1.44±0.023de</td>
<td>1.29±0.022eh</td>
</tr>
<tr>
<td>T3</td>
<td>1.56±0.015bc</td>
<td>1.35±0.015e-h</td>
</tr>
<tr>
<td>T4</td>
<td>1.68±0.024a</td>
<td>1.41±0.019df-f</td>
</tr>
<tr>
<td>Means</td>
<td>1.51±0.038a</td>
<td>1.33±0.018b</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td></td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100% wheat flour (Control)
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
Figure 4.11 Effect of composite flour on bread crude fat (%) 

Figure 4.12 Effect of composite flour on bread crude fiber (%) 

\[ T_0 = 0\% \text{ quinoa flour} + 100\% \text{ wheat flour}, \quad T_1 = 5\% \text{ quinoa flour} + 95\% \text{ wheat flour}, \]
\[ T_2 = 10\% \text{ quinoa flour} + 90\% \text{ wheat flour}, \quad T_3 = 15\% \text{ quinoa flour} + 85\% \text{ wheat flour}, \]
\[ T_4 = 20\% \text{ quinoa flour} + 80\% \text{ wheat flour} \]
It is also evident from results that the fiber varied from 1.33±0.014 to 1.51±0.038 among different lines. The highest fiber (1.51±0.038%) was observed in *C. quinoa* V7 followed by *C. quinoa* V1 (1.47±0.034%) and *C. quinoa* V9 (1.33±0.014%) while minimum fiber (1.33±0.018%) was observed in *C. quinoa* V2. The results also showed a non-significant increasing trend in fiber with the increase of quinoa flour in wheat flour. As for as interaction of quinoa lines with treatments is concerned all quinoa lines showed increasing trend in bread fiber from T1 to T4. Maximum increase was observed in *C. quinoa* V7. Figure 4.12 showed that *C. quinoa* V9 gave value in accordance to control at T1 and T4 while *C. quinoa* V2 gave better results at T2 and T3 respectively. The results are in line to the findings of Ade-Omowaye *et al.* (2008), who determined that notable enhancement in fiber content (167-967%) with the increase level of non-wheat source for bread preparation.

### 4.12 Effect of composite flour on sensory evaluation of bread

Quality assessment for new product development sensory evaluation is an imperative criteria to fulfill consumer requirements. New product must provide satisfaction and pleasure to the consumer for adoption to become a part of their eating practice. Due to this, prepared bread with the supplementation of quinoa flour were assessed for its numerous internal and external characteristics. Bread was assessed by panel of judges and obtained results have been discussed below.

#### 4.12.1 External Characteristics

##### 4.12.1.1 Bread loaf volume

Analysis of variance (Table 4.47) regarding loaf volume of bread showed highly significant variation among all experimental measures when compared to control. Results further revealed that quinoa lines caused significant effect and treatments also depicted highly significant variation on bread loaf volume while interaction of quinoa lines and treatments caused non-significant variation on bread loaf volume.

It is apparent from the results given in Table 4.48 that bread loaf volume in different treatments ranged from 6.27±0.067 to 7.29±0.074. Significantly the highest loaf volume was observed for T1 (7.29±0.074) followed by T2 (6.95±0.057) and T3 (6.79±0.045). The lowest loaf volume (6.27±0.067) was found in T4 while control have 8.00±0.058. All quinoa lines showed at best at T1 (5% substitution) as its value regarding bread loaf volume is closer to control (Figure 4.13).

It is also evident from results that the loaf volume varied from 6.68±0.112 to 6.95±0.132 among different quinoa lines. The highest loaf volume (6.95±0.132) was observed in *C.*
### Table 4.47 Analysis of variance for loaf volume

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.70676**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>3.89824**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.14833*</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>2.18500**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.04556NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.03471</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

### Table 4.48 Means for loaf volume (Lines x Treatment interaction)

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>7.47±0.145</td>
<td>7.37±0.145</td>
</tr>
<tr>
<td>T2</td>
<td>7.17±0.145</td>
<td>6.97±0.033</td>
</tr>
<tr>
<td>T3</td>
<td>6.70±0.115</td>
<td>6.80±0.100</td>
</tr>
<tr>
<td>T4</td>
<td>6.47±0.145</td>
<td>6.30±0.115</td>
</tr>
<tr>
<td>Means</td>
<td>6.95±0.132a</td>
<td>6.86±0.124ab</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td></td>
</tr>
</tbody>
</table>

Means sharing similar letter statistically non-significant (P>0.05).

T₀= 0% quinoa flour + 100 % wheat flour  
T₁= 5% quinoa flour + 95% wheat flour  
T₂= 10% quinoa flour + 90% wheat flour  
T₃= 15% quinoa flour + 85% wheat flour  
T₄= 20% quinoa flour + 80% wheat flour
quinoa V7 followed by C. quinoa V2 (6.86±0.124) and C. quinoa V1 (6.81±0.128) while minimum loaf volume (6.68±0.112) was observed in C. quinoa V9. On all concentration used from T₁ to T₄ C. quinoa V7 showed results closer to control then other quinoa lines. The results also showed a significant decreasing trend in loaf volume with the increase of quinoa flour in wheat flour. As for as interaction of lines with treatments is concerned all lines showed decreasing trend in bread loaf volume from T₁ to T₄. Result of current research supported by the findings of Vittadini and Vodovotz (2003) who reported that soy flour added bread has lower loaf volume as compared to the 100% wheat flour bread. The gradual reduction in loaf volume which increased in supplementation level of soy flour in wheat flour was also observed. This reduction might be due to lower and dilution in gluten contents of wheat and soy composite flour. It is previously reported that quinoa flour does not have gluten forming protein which is present in wheat flour (Lorenz, 1990; Lorenz and Coulter, 1991). The reason for the gradual decrease in the loaf volume by the addition of quinoa might be due the cell structure of loaf which are unable to hold gas during proofing and baking of dough.

4.12.1.2 Bread crust color

Mean squares of crust color of bread have been presented in Table 4.49. It revealed highly significant difference in crust color among all treatments when compared with control. Other parameters of ANOVA i.e. treatments, quinoa lines, and its interaction proved as significant effectors on crust color of bread. Quinoa lines caused highly significant variation in crust color similarly treatments and interaction of lines and treatments also showed highly significant variation on crust color of bread.

It is observable from the mean results given in Table 4.50 that crust color in different treatments ranged from 4.75±0.394 to 6.51±0.159. Significantly the highest crust color was observed for T₁ (6.51±0.159) followed by T₂ (5.89±0.347) and T₃ (5.13±0.268), however, the lowest value of crust color (4.75±0.394) was found in T₄ (20 % substitution). It is also evident from results that the crust color varied from 4.39±0.334 to 6.52±0.155 among different quinoa lines. The highest crust color (6.52±0.155) was observed in C. quinoa V7 followed by C. quinoa V9 (6.49±0.164) and C. quinoa V1 (4.88±0.222) while minimum crust color (4.39±0.334) was observed in C. quinoa V2.

As for as interaction of quinoa lines with treatments is concerned all quinoa lines showed decreasing trend in crust color from T₁ to T₄. In 5% replacement, C. quinoa V9 showed the best results among quinoa lines and at 10%, 15% and 20% substitution C. quinoa V7
### Table 4.49 Analysis of variance for crust color of bread

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>5.472**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>17.151**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>14.468**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>7.417**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.527**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.028</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

### Table 4.50 Means for crust color of bread prepared from composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>7.00±0.115&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.03±0.033&lt;sup&gt;l&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;</td>
<td>7.03±0.088&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.53±0.145&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;3&lt;/sub&gt;</td>
<td>6.00±0.058&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.00±0.115&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;4&lt;/sub&gt;</td>
<td>6.03±0.033&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.00±0.115&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Means</td>
<td>6.52±0.155&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.39±0.334&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;0&lt;/sub&gt;</td>
<td>100% Straight grade wheat flour</td>
<td></td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T<sub>0</sub> = 0% quinoa flour + 100% wheat flour  
T<sub>1</sub> = 5% quinoa flour + 95% wheat flour  
T<sub>2</sub> = 10% quinoa flour + 90% wheat flour  
T<sub>3</sub> = 15% quinoa flour + 85% wheat flour  
T<sub>4</sub> = 20% quinoa flour + 80% wheat flour
Figure 4.13 Effect of composite flour on loaf volume of bread

Figure 4.14 Effect of composite flour on crust color of bread

T₀ = 0% quinoa flour + 100% wheat flour, T₁ = 5% quinoa flour + 95% wheat flour
T₂ = 10% quinoa flour + 90% wheat flour, T₃ = 15% quinoa flour + 85% wheat flour
T₄ = 20% quinoa flour + 80% wheat flour
depicted better results than other quinoa lines regarding crust color. The maximum increase was observed in *C. quinoa* V7. Results also revealed that lines, treatments, and interaction of both lines and treatments caused highly significant variation in bread crust color (Figure 4.14). The darkened color of crust may be due to the milliard reaction taking place during baking of loaves, due to high lysine contents, it may also due to the color of flour. Ory and Conkerton (1983) observed that the addition of peanut flour in the flour of wheat showed significant effect on the crust color. Chavan *et al.* (1993) observed that the score assigning to crust color declined as increased in the supplemented level of peanut flour. Poor quality and color of bread can resulted due to absence of gluten rather than pre-baking of dough (Gallagher *et al.*, 2004).

### 4.12.1.3 Symmetry of form

The statistical data regarding bread symmetry (Table 4.51) showed that highly significant variation in bread symmetry among all experiment and analogous differences were observed in supplemented bread as compared to control. Results further revealed that quinoa lines, and interaction of both quinoa lines and treatments caused non-significant variation on bread symmetry, however treatments have significant effect on bread symmetry.

It is apparent from the results (Table 4.52) that bread symmetry in different treatments ranged from 2.08±0.045 to 2.44±0.020. Significantly the highest bread symmetry (2.44±0.020) was observed for T₁ followed by T₂ (2.37±0.040) and T₃ (2.20±0.051). The lowest bread symmetry (2.08±0.045) was found in T₄ among different treatments (Figure 4.15) that all quinoa lines have best result on 5 % substitution.

It is also evident from data that the bread symmetry varied from 2.22±0.066 to 2.32±0.044 among different quinoa lines. The highest bread symmetry (2.32±0.044) was observed in *C. quinoa* V1 followed by *C. quinoa* V2 (2.30±0.064) and *C. quinoa* V9 (2.24±0.053) whilst the minimum bread symmetry (2.22±0.066) was observed in *C. quinoa* V7.

The results also showed a significant decreasing trend in bread symmetry with the increase of quinoa flour in wheat flour. The lines showed a unique behavior regarding bread symmetry as *C. quinoa* V7 and *C. quinoa* V9 has similar effect and *C. quinoa* V1 and *C. quinoa* V2 has similar effect. As for as interaction is concerned, all flours showed decreasing trend down the group from T₁ to T₄. The maximum decreasing trend was observed in *C. quinoa* V7. Result of current finding are supported by Gomez *et al.* (2008) who reported that symmetry reduced by addition of non-wheat flour into composite flour.
Table 4.51 Analysis of variance for bread symmetry

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.118**</td>
</tr>
<tr>
<td>Control x others</td>
<td>1</td>
<td>0.742**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.029 NS</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.318**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.012 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.022</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); ** = Highly significant (P<0.01)

Table 4.52 Means for bread symmetry (Lines x Treatment interaction)

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>2.47±0.033</td>
<td>2.45±0.029</td>
</tr>
<tr>
<td>T2</td>
<td>2.37±0.033</td>
<td>2.40±0.115</td>
</tr>
<tr>
<td>T3</td>
<td>2.07±0.088</td>
<td>2.23±0.145</td>
</tr>
<tr>
<td>T4</td>
<td>1.97±0.033</td>
<td>2.13±0.145</td>
</tr>
<tr>
<td>Means</td>
<td>2.22±0.066^a</td>
<td>2.30±0.064^a</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td>2.783±0.012</td>
</tr>
</tbody>
</table>

Means sharing similar are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
4.12.1.4 Evenness of bake
The mean squares of evenness of bake have been presented in (Table 4.53) revealed highly significant difference in evenness of bake among all treatments in comparison with control. Statistical splitting revealed that only treatments caused this variation as quinoa lines and interaction of quinoa lines and treatment didn’t show their effect on evenness of bake considering alone.

Mean results of evenness of bake have been given in Table 4.54. It showed that evenness of bake in different treatments ranged from 1.76±0.031 to 2.20±0.030. Significantly the highest evenness of bake (2.20±0.030) was observed for T₁ followed by T₂ (2.10±0.018) and T₃ (1.93±0.031). The lowest evenness of bake (1.76±0.031) was found in T₄. Comparing the results of evenness of bake of different treatments with control proved that substituting at 5 % quinoa flour as in T₁ of any variety showed values closer to control (Figure 4.16).

It is also evident from results that the evenness of bake varied from 1.96±0.068 to 2.04±0.047 among different quinoa lines. The highest evenness of bake (2.04±0.047) was observed in C. quinoa V7 followed by C. quinoa V2 (2.03±0.054) and C. quinoa V1 (1.98±0.053) while the minimum (1.96±0.068) was observed in C. quinoa V9. As for as interaction of lines with treatments is concerned all quinoa lines showed decreasing trend in evenness of bake from T₁ to T₄. The maximum decrease in evenness of bake was observed in C. quinoa V9 from 5 % to 20 % substitution which is 0.56.

4.12.1.5 Character of crust
The values of mean squares for character of crust have been presented in Table 4.55. It showed highly significant difference on character of bread crust among all treatments in comparing with control. Statistical results revealed that only treatments caused variation in character of crust as quinoa lines and interaction of treatments with quinoa lines showed non-significant effect on character of crust.

The mean values of character of crust have been given in Table 4.56 revealed that character of crust in different treatments ranged from 2.01±0.029 to 2.37±0.018. Significantly the highest character of crust (2.37±0.018) was observed for treatment T₁ followed by treatment T₂ (2.28±0.045) and T₃ (2.20±0.017). The lowest character of crust (2.01±0.029) was found in treatment T₄. Comparing the results of character of crust of different treatments with control proved that substituting 5 % quinoa flour as in T₁ of any variety have values closer to control (Figure 4.17).
### Table 4.5.3 Analysis of variance for evenness of bake

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.10612**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>0.25482**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.01809 NS</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.44742**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.00517 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.01036</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); ** = Highly significant (P<0.01)

### Table 4.5.4 Means for evenness of bake of bread prepared from composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>2.20±0.058</td>
<td>2.21±0.116</td>
</tr>
<tr>
<td>T2</td>
<td>2.15±0.029</td>
<td>2.13±0.033</td>
</tr>
<tr>
<td>T3</td>
<td>1.97±0.033</td>
<td>1.95±0.029</td>
</tr>
<tr>
<td>T4</td>
<td>1.83±0.033</td>
<td>1.82±0.044</td>
</tr>
<tr>
<td>Means</td>
<td>2.04±0.047a</td>
<td>2.03±0.054a</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td>2.300±0.115</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour  
T1= 5% quinoa flour + 95% wheat flour  
T2= 10% quinoa flour + 90% wheat flour  
T3= 15% quinoa flour + 85% wheat flour  
T4= 20% quinoa flour + 80% wheat flour
Figure 4.15 Effect of composite flour on bread symmetry

Figure 4.16 Effect of composite flour on evenness of bake

$T_0 = 0\%$ quinoa flour + $100\%$ wheat flour, $T_1 = 5\%$ quinoa flour + $95\%$ wheat flour
$T_2 = 10\%$ quinoa flour + $90\%$ wheat flour, $T_3 = 15\%$ quinoa flour + $85\%$ wheat flour
$T_4 = 20\%$ quinoa flour + $80\%$ wheat flour
It is also evident from results that the character of crust varied from 2.16±0.059 to 2.25±0.049 among different quinoa lines. The highest character of crust (2.25±0.049) was observed in *C. quinoa* V7 followed by *C. quinoa* V1 (2.24±0.038) and *C. quinoa* V2 (2.22±0.046) while minimum (2.16±0.059) was observed in *C. quinoa* V9. As for as interaction of lines with treatments is concerned all quinoa lines showed decreasing trend in character of crust from T1 to T4.

### 4.12.1.6 Break and shred

Means squares (Table 4.57) regarding break and shred of bread showed highly significant variations in break and shred in all combinations and similar differences were observed in supplemented bread as compared to control. Statistical study further revealed that quinoa lines and treatments have highly significant variation on break and shred, however their interaction showed non-significant effect.

It is evident from the results (Table 4.58) that break and shred in different treatments ranged from 1.96±0.047 to 2.37±0.040. Significantly the highest value (2.37±0.040) for break and shred, was observed for T1 followed by T2 (2.26±0.043) and T3 (2.12±0.042). The lowest break and shred (1.96±0.047) was found in T4 and control have 2.533±0.033. It is also evident from results that the break and shred varied from 2.04±0.056 to 2.30±0.054 among different quinoa lines. The highest value (2.30±0.054) of break and shred was observed in *C. quinoa* V7 followed by *C. quinoa* V2 (2.21±0.054) and *C. quinoa* V1 (2.16±0.065) while the minimum break and shred (2.04±0.056) was observed in *C. quinoa* V9. On all concentrations used against all quinoa lines *C. quinoa* V7 showed better than other quinoa lines. The results also showed a significant decreasing trend in break and shred with the increase of quinoa flour in wheat flour (Figure 4.18).

### 4.12.2 Internal Characteristics

#### 4.12.2.1 Grain of bread crumb

The results regarding the mean squares for (Table 4.59) crumb grain of bread depicted highly momentous differences in all trials and similar variations were observed in supplemented bread as compared to control. Statistical data further explicated that quinoa lines, treatments, and interaction of both quinoa lines and treatments caused highly significant variations in bread crumb grain.

It is apparent from the results given in Table 4.60 that bread crumb grain in different treatments ranged from 4.76±0.130 to 6.63±0.124. Significantly the highest crumb grain (6.63±0.124) was observed for T1 followed by T2 (6.01±0.190) and T3 (5.50±0.190). The
### Table 4.55 Analysis of variance for character of crust

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.078**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>0.227**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.017 NS</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.281**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.013 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.010686</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); ** = Highly significant (P<0.01)

### Table 4.56 Means for character of bread crust prepared from composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T₁</td>
<td>2.37±0.033</td>
<td>2.37±0.033</td>
</tr>
<tr>
<td>T₂</td>
<td>2.38±0.117</td>
<td>2.30±0.115</td>
</tr>
<tr>
<td>T₃</td>
<td>2.17±0.033</td>
<td>2.17±0.033</td>
</tr>
<tr>
<td>T₄</td>
<td>2.07±0.033</td>
<td>2.05±0.029</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td><strong>2.25±0.049&lt;sup&gt;a&lt;/sup&gt;</strong></td>
<td><strong>2.22±0.046&lt;sup&gt;a&lt;/sup&gt;</strong></td>
</tr>
<tr>
<td>T₀</td>
<td>100% Straight grade wheat flour</td>
<td>2.500±0.115</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T₀ = 0% quinoa flour + 100% wheat flour
T₁ = 5% quinoa flour + 95% wheat flour
T₂ = 10% quinoa flour + 90% wheat flour
T₃ = 15% quinoa flour + 85% wheat flour
T₄ = 20% quinoa flour + 80% wheat flour

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Table 4.57 Analysis of variance for break and shred

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.124884**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>0.358346**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.134514**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.385347**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.008912 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.014902</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.58 Means for break and shred of bread

<table>
<thead>
<tr>
<th>Treat</th>
<th>C. quinoa V7</th>
<th>C. quinoa V2</th>
<th>C. quinoa V1</th>
<th>C. quinoa V9</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>2.45±0.029</td>
<td>2.40±0.058</td>
<td>2.37±0.145</td>
<td>2.27±0.033</td>
<td>2.37±0.040a</td>
</tr>
<tr>
<td>T2</td>
<td>2.37±0.033</td>
<td>2.33±0.033</td>
<td>2.28±0.060</td>
<td>2.07±0.088</td>
<td>2.26±0.043a</td>
</tr>
<tr>
<td>T3</td>
<td>2.30±0.115</td>
<td>2.07±0.033</td>
<td>2.07±0.033</td>
<td>2.03±0.033</td>
<td>2.12±0.042b</td>
</tr>
<tr>
<td>T4</td>
<td>2.07±0.088</td>
<td>2.03±0.088</td>
<td>1.93±0.088</td>
<td>1.80±0.058</td>
<td>1.96±0.047c</td>
</tr>
<tr>
<td>Means</td>
<td>2.30±0.054a</td>
<td>2.21±0.054a</td>
<td>2.16±0.065ab</td>
<td>2.04±0.056b</td>
<td></td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
Figure 4.17 Effect of composite flour on character of crust

Figure 4.18 Effect of composite flour on break and shred of bread

$T_0 = 0\%$ quinoa flour + $100\%$ wheat flour, $T_1 = 5\%$ quinoa flour + $95\%$ wheat flour
$T_2 = 10\%$ quinoa flour + $90\%$ wheat flour, $T_3 = 15\%$ quinoa flour + $85\%$ wheat flour
$T_4 = 20\%$ quinoa flour + $80\%$ wheat flour
lowest crumb grain (4.76±0.130) was found in T4. It is also evident from results that the crumb grain varied from 4.89±0.227 to 6.15±0.223 among different quinoa lines. The highest crumb grain (6.15±0.223) was observed in C. quinoa V2 followed by C. quinoa V7 (5.99±0.213) and C. quinoa V1 (5.86±0.202) while minimum crumb grain (4.89±0.227) was observed in C. quinoa V9. The results also showed a significant decreasing trend in crumb grain with the increase of quinoa flour in wheat flour. The quinoa lines showed a unique behavior regarding crumb grain for C. quinoa V1 and C. quinoa V9 has similar effect while C. quinoa V7 and C. quinoa V2 has different effect. As for as interaction is concerned, all quinoa lines showed decreasing trend in the group from T1 to T4. The maximum decreasing trend was observed in C. quinoa V9. The C. quinoa V2 gave better value of crumb grain from T1 to T4 then other quinoa lines as depicted in Figure 4.19. The results of current finding are supported by Hussain et al. (2009) who observed that scores given to bread grain were significantly affected by the amount of flaxseed replacement in straight grade flour. Fleming and Sosulski (1977) also explicated that concentrated plant protein deteriorates the crumb grain in proportion to its quantity of used to replace the wheat flour.

4.12.1.1 Color of bread crumb

The mean squares for color of bread are presented in Table 4.61Error! Reference source not found.. It is prominent from the results that highly significant variations were observed in crumb color in all experiments and similar differences were observed in supplemented bread as compared to control. Results further revealed that quinoa lines, treatments, and interaction of both quinoa lines and treatments instigated highly significant variations in bread crumb color.

It is apparent from the results given in Table 4.62 that bread crumb color in different treatments ranged from 4.03±0.318 to 6.26±0.253. Significantly the highest crumb color (6.26±0.253) was observed for T1 followed by T2 (5.27±0.257) and T3 (4.77±0.395), while the lowest crumb color (4.03±0.318) was found in T4. It is also evident from results that the crumb color varied from 3.63±0.288 to 6.02±0.216 among different lines. The highest crumb color (6.02±0.213) was observed in C. quinoa V7 and C. quinoa V9 followed by C. quinoa V1 (4.65±0.292) whereas minimum crumb color (3.63±0.288) was observed in C. quinoa V2. The results also showed a significant decreasing trend in crumb color with the increase of quinoa flour in wheat flour. The lines showed a unique behavior regarding crumb color for instance; C. quinoa V7 and C. quinoa V9 has similar effect while C. quinoa
Table 4.59 Analysis of variance for crumb grain

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>3.134**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>14.640**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>3.856**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>7.501**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.158**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.024</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.60 Means for bread crumb grain

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T&lt;sub&gt;0&lt;/sub&gt;</td>
<td>100% Straight grade wheat flour</td>
<td>8.00±0.058</td>
</tr>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>6.97±0.033&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.00±0.100&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;</td>
<td>6.03±0.067&lt;sup&gt;de&lt;/sup&gt;</td>
<td>6.53±0.088&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;3&lt;/sub&gt;</td>
<td>5.97±0.088&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>6.03±0.088&lt;sup&gt;de&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;4&lt;/sub&gt;</td>
<td>5.00±0.115&lt;sup&gt;h&lt;/sup&gt;</td>
<td>5.03±0.067&lt;sup&gt;gh&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td>5.99±0.213&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.15±0.223&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

T<sub>0</sub>= 0% quinoa flour + 100 % wheat flour
T<sub>1</sub>= 5% quinoa flour + 95% wheat flour
T<sub>2</sub>= 10% quinoa flour + 90% wheat flour
T<sub>3</sub>= 15% quinoa flour + 85% wheat flour
T<sub>4</sub>= 20% quinoa flour + 80% wheat flour
V1 and *C. quinoa* V2 showed different effects. As for as interaction is concerned all quinoa lines showed decreasing trend from T\textsubscript{1} to T\textsubscript{4}. Maximum decreasing trend was observed in *C. quinoa* V1. In 1\textsuperscript{st} and 2\textsuperscript{nd} treatment *C. quinoa* V7 and *C. quinoa* V9 gave best results while in 3\textsuperscript{rd} treatment *C. quinoa* V9 and in 4\textsuperscript{th} treatment *C. quinoa* V7 expounded best results being closer to control’s as it can be viewed from Figure 4.20. Chavan *et al.* (1993) observed that the score assigning to color of crumb of bread decreased as the supplementation level of peanut flour increased. Fleming and Sosulski (1977) also observed that concentrated plant protein significantly affect assigned score of crumb color in proportion to quantity of concentrated plant protein used to replace the wheat flour. The darkening of color is due to the milliard reaction. Alvarez-Jubete *et al.* (2010b) investigated that bread prepared from pseudo-cereal characterized by a significantly darker crumb color in comparison with the control.

### 4.12.1.2 Bread aroma

Analysis of variance (Table 4.63) regarding aroma of bread showed highly significant variation in bread aroma in all experimental measures and also similar trend was observed in supplemented bread as compared to control. Results further exposed that quinoa lines, treatments, and interaction of both quinoa lines and treatments instigated highly significant variation in bread aroma.

It is evident from the results given in Table 4.64 that bread aroma in different treatments ranged from 5.88±0.166 to 7.00±0.033. Significantly the highest bread aroma (7.00±0.033) was observed for T\textsubscript{1} followed by T\textsubscript{2} (6.63±0.134) and T\textsubscript{3} (5.90±0.170). The lowest bread aroma (5.88±0.166) was found in T\textsubscript{4}. It is also evident from results that the bread aroma varied from 5.75±0.249 to 6.77±0.078 among different lines. The highest bread aroma (6.77±0.078) was observed in *C. quinoa* V7 followed by *C. quinoa* V1 (6.51±0.154) and *C. quinoa* V2 (6.38±0.128) while minimum bread aroma (5.75±0.249) was observed in *C. quinoa* V9. The results also showed a significant decreasing trend in bread aroma with increasing quinoa flour in wheat flour. The quinoa lines showed a inimitable comportment regarding bread aroma as all lines showed distinctively different values from each other. As for as interaction is concerned, all lines showed decreasing trend in the group from T\textsubscript{1} to T\textsubscript{4}. At 5 \% substitution, all quinoa lines showed similar behavior while at 10 \%, 15\% and 20 \% *C. quinoa* V7 elucidated good results as given in Figure 4.21. Chavan *et al.* (1993) observed that the score assigning to aroma of bread decreased as the supplementation level of peanut flour increased. Moreover, Hussain *et al.*
(2009) observed that scores given to aroma of breads were affected significantly by the levels of flaxseed supplementation in straight grade flour.

**4.12.1.3 Bread taste**

Analysis of variance regarding the taste of bread have been presented in Table 4.65, showed highly significant difference in all parameters. It reflects highly significant variation in bread taste of all treatments. Furthermore, it has been suggested that variation was due to quinoa lines. Mean values regarding the taste of quinoa supplemented bread has been presented in Table 4.66. The mean values of all the treatments showed significant differences with a treatments and their interaction. decreasing trend from T₁ to T₄. The mean values of T₁, T₂, T₃ and T₄ were 10.52±0.164, 9.24±0.148, 8.63±0.244 and 7.99±0.219, respectively. The highest value was 10.52±0.164 of T₁ while the lowest was 7.99±0.219 of T₄. The mean values for taste of all the quinoa lines showed significant differences from each other. It is also evident from results that the bread taste varied from 8.49±0.343 to 10.00±0.219 among different quinoa lines. The highest bread taste (10.00±0.219) was observed in *C. quinoa* V₂ followed by *C. quinoa* V₁ (9.01±0.373) and *C. quinoa* V₇ (8.88±0.235) while minimum bread taste (8.49±0.343) was observed in *C. quinoa* V₉.

The results also showed a significant decreasing trend in bread taste with the increase of quinoa flour in wheat flour. As respect to interaction, all quinoa lines showed decreasing trend down the group from T₁ to T₄ except *C. quinoa* V₂ and *C. quinoa* V₁. The maximum decrease was observed in *C. quinoa* V₁ and in *C. quinoa* V₉. Figure 4.22 showed that *C. quinoa* V₁ and *C. quinoa* V₂ gave best results in T₁ while *C. quinoa* V₂ gave best results in T₂, T₃ and T₄ being more closer value to control. Chavan et al. (1993) observed that the score assigning to taste of bread decreased as the supplementation level of peanut flour increased. Hussain et al. (2009) observed that scores given to breads taste were significantly influenced by the supplemented levels of flaxseed in straight grade flour.

**4.12.1.4 Mastication of bread**

Analysis of variance (Table 4.67) regarding mastication of bread showed highly significant variations in bread mastication in all experimental measures and similar variations were observed in supplemented bread as compared to control. Results further revealed that quinoa lines, treatments, and their interaction caused highly significant effect on bread mastication.

It is manifest from the results given in Table 4.68 that bread mastication in different
Table 4.61 Analysis of variance for bread crumb color

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>5.801**</td>
</tr>
<tr>
<td>Control x Others</td>
<td>1</td>
<td>10.782**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>16.130**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>10.538**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.225**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.021</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.62 Means for bread crumb color (Lines x Treatment interaction)

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>7.00±0.100a</td>
<td>5.00±0.058c</td>
</tr>
<tr>
<td>T2</td>
<td>6.03±0.088b</td>
<td>4.00±0.058d</td>
</tr>
<tr>
<td>T3</td>
<td>6.00±0.100b</td>
<td>3.00±0.100f</td>
</tr>
<tr>
<td>T4</td>
<td>5.03±0.033c</td>
<td>2.53±0.033g</td>
</tr>
<tr>
<td>Means</td>
<td>6.02±0.213a</td>
<td>3.63±0.288c</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td></td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T0 = 0% quinoa flour + 100 % wheat flour
T1 = 5% quinoa flour + 95% wheat flour
T2 = 10% quinoa flour + 90% wheat flour
T3 = 15% quinoa flour + 85% wheat flour
T4 = 20% quinoa flour + 80% wheat flour
Figure 4.19 Effect of composite flour on grain of breads crumb

Figure 4.20 Effect of composite flour on color of bread crumb

$T_0$ = 0% quinoa flour + 100% wheat flour, $T_1$ = 5% quinoa flour + 95% wheat flour
$T_2$ = 10% quinoa flour + 90% wheat flour, $T_3$ = 15% quinoa flour + 85% wheat flour
$T_4$ = 20% quinoa flour + 80% wheat flour
Table 4.63 Analysis of variance for bread aroma prepared from composite flour

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>1.7554**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>7.6676**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>2.2391**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>3.6735**</td>
</tr>
<tr>
<td>L × T</td>
<td>9</td>
<td>0.2979**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.0182</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.64 Means for bread aroma prepared from composite flour

<table>
<thead>
<tr>
<th>Quinoa Lines</th>
<th>C. quinoa V7</th>
<th>C. quinoa V2</th>
<th>C. quinoa V1</th>
<th>C. quinoa V9</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treat.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T&lt;sub&gt;0&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.00±0.058</td>
</tr>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>7.00±0.058&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.00±0.058&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.00±0.115&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.00±0.058&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.00±0.033&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;</td>
<td>7.03±0.033&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.50±0.058&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.00±0.115&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.97±0.033&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.63±0.134&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;3&lt;/sub&gt;</td>
<td>6.53±0.033&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.03±0.088&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.03±0.033&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.00±0.058&lt;sup&gt;d&lt;/sup&gt;</td>
<td>5.90±0.170&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;4&lt;/sub&gt;</td>
<td>6.50±0.058&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.00±0.115&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.00±0.115&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.03±0.120&lt;sup&gt;d&lt;/sup&gt;</td>
<td>5.88±0.166&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Means</td>
<td>6.77±0.078&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.38±0.128&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.51±0.154&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.75±0.249&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T<sub>0</sub>= 0% quinoa flour + 100 % wheat flour
T<sub>1</sub>= 5% quinoa flour + 95% wheat flour
T<sub>2</sub>= 10% quinoa flour + 90% wheat flour
T<sub>3</sub>= 15% quinoa flour + 85% wheat flour
T<sub>4</sub>= 20% quinoa flour + 80% wheat flour
Table 4.65 Analysis of variance for bread taste

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>5.312**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>23.848**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>4.956**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>13.923**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.501**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.039</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.66 Means for bread taste prepared from composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>10.00±0.153b</td>
<td>11.03±0.033a</td>
</tr>
<tr>
<td>T2</td>
<td>9.00±0.289c</td>
<td>10.00±0.115b</td>
</tr>
<tr>
<td>T3</td>
<td>8.50±0.115cd</td>
<td>9.97±0.033b</td>
</tr>
<tr>
<td>T4</td>
<td>8.00±0.058d</td>
<td>9.00±0.058c</td>
</tr>
<tr>
<td>Means</td>
<td>8.88±0.235b</td>
<td>10.00±0.219a</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td>12.00±0.11</td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
Figure 4.21 Effect of composite flour on bread aroma

Figure 4.22 Effect of composite flour on bread taste

$T_0=0\%$ quinoa flour + $100\%$ wheat flour, $T_1=5\%$ quinoa flour + $95\%$ wheat flour
$T_2=10\%$ quinoa flour + $90\%$ wheat flour, $T_3=15\%$ quinoa flour + $85\%$ wheat flour
$T_4=20\%$ quinoa flour + $80\%$ wheat flour
treatments ranged from 6.14±0.074 to 7.11±0.041. Significantly the highest bread mastication (7.11±0.041) was observed for T₁ followed by T₂ (7.01±0.036) and T₃ (6.49±0.156), while the lowest bread mastication (6.14±0.074) was found in T₄. It is also evident from results that the bread mastication varied from 6.52±0.154 to 6.89±0.066 among different quinoa lines. The highest bread mastication (6.89±0.066) was observed in C. quinoa V2 followed by C. quinoa V9 (6.80±0.148) and C. quinoa V1 (6.55±0.172) whereas minimum bread mastication (6.52±0.154) was observed in C. quinoa V7.

The results also showed a significant decreasing trend in bread mastication with the increase of quinoa flour in wheat flour. The lines showed a unique behavior regarding bread mastication as C. quinoa V7 and C. quinoa V1 has similar effect and C. quinoa V2 and C. quinoa V9 has also similar effect. The maximum decreasing trend was observed in C. quinoa V1. At 5 % substitution C. quinoa V1 and C. quinoa V2 at 10 % and 20 % substitution behaved best while C. quinoa V2 and C. quinoa V9 show better results at 15 % substitution as it can be viewed from Figure 4.23. The results of the present study are comparable with findings of Chavan et al. (1993) who observed that the score assigning to taste of bread decreased as the supplementation level of peanut flour increased. Furthermore, Hussain et al. (2009) observed that scores given to taste of breads were affected significantly by the levels of flaxseed supplementation in straight grade flour.

4.12.1.5 Bread texture

Analysis of variance (Table 4.69) regarding texture of bread showed that highly significant variation in bread texture in all experimental measures and similar variations were observed in supplemented bread as compared to control. Results further revealed that quinoa lines, treatments, and their interaction caused highly significant variation on bread texture.

It is evident from the results given in Table 4.70 that bread texture in different treatments ranged from 7.13±0.168 to 9.52±0.157. Significantly the highest bread texture (9.52±0.157) was observed for T₁ followed by T₂ (8.48±0.154) and T₃ (7.75±0.133). The lowest bread texture (7.13±0.168) was found in T₄. It is also evident from results that the bread texture varied from 7.63±0.291 to 8.51±0.339 among different lines. The highest bread texture (8.51±0.339) was observed in C. quinoa V7 followed by C. quinoa V2 (8.48±0.340) and C. quinoa V9 (8.27±0.139) while minimum bread texture (7.63±0.291) was observed in C. quinoa V1.

The results also showed a significant decreasing trend in bread texture with increasing quinoa flour in wheat flour. The lines showed a unique behavior regarding bread texture.
Table 4.67 Analysis of variance for bread mastication

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>1.006**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>4.862**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.412**</td>
</tr>
<tr>
<td>Treatment (T)</td>
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<td>2.467**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.288**</td>
</tr>
<tr>
<td>Error</td>
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<td>0.016</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
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</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.68 Means for bread mastication prepared from composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>7.03±0.033a</td>
<td>7.00±0.058a</td>
</tr>
<tr>
<td>T2</td>
<td>7.00±0.115a</td>
<td>7.04±0.037a</td>
</tr>
<tr>
<td>T3</td>
<td>6.00±0.058c</td>
<td>7.00±0.058a</td>
</tr>
<tr>
<td>T4</td>
<td>6.03±0.033c</td>
<td>6.53±0.033b</td>
</tr>
<tr>
<td>Means</td>
<td>6.52±0.154b</td>
<td>6.89±0.066a</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td></td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
Figure 4.23 Effect of composite flour on mastication of bread

Figure 4.24 Effect of composite flour on bread texture

T₀ = 0% quinoa flour + 100% wheat flour, T₁ = 5% quinoa flour + 95% wheat flour
T₂ = 10% quinoa flour + 90% wheat flour, T₃ = 15% quinoa flour + 85% wheat flour
T₄ = 20% quinoa flour + 80% wheat flour
**Table 4.69** Analysis of variance for bread texture

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>5.579**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>39.618**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>2.035**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>12.610**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.635**</td>
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<tr>
<td>Error</td>
<td>34</td>
<td>0.020</td>
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<tr>
<td>Total</td>
<td>50</td>
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</table>

** = Highly significant (P<0.01)

**Table 4.70** Means for bread texture

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>10.03±0.088a</td>
<td>10.00±0.115a</td>
</tr>
<tr>
<td>T2</td>
<td>9.00±0.058b</td>
<td>8.97±0.067b</td>
</tr>
<tr>
<td>T3</td>
<td>7.97±0.067c</td>
<td>7.97±0.067c</td>
</tr>
<tr>
<td>T4</td>
<td>7.03±0.033d</td>
<td>7.00±0.115d</td>
</tr>
<tr>
<td>Means</td>
<td>8.51±0.339a</td>
<td>8.48±0.340a</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td></td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
for instance, *C. quinoa* V7 and *C. quinoa* V2 has similar effect and *C. quinoa* V1 and *C. quinoa* V9 has distinguished effect. The interaction depicted that all lines showed decreasing trend from T1 to T4. The maximum decreasing trend was observed in *C. quinoa* V1. The best results regarding bread texture explicated by different quinoa lines on different treatments as *C. quinoa* V7 at T1 and T2 and *C. quinoa* V9 at T3 and T4 gave best results as mentioned in Figure 4.24.

### 4.12.3 Total score of bread

Analysis of variance (Table 4.71) regarding total score of bread showed that highly significant variation in bread total score in all experimental measures and similar variations were also observed in supplemented bread as compared to control. Results revealed that quinoa lines, treatments, and interaction of both quinoa lines and treatments caused highly significant variation on bread total score.

It is perceivable from the results given in Table 4.72 that bread total score in different treatments ranged from 54.68±0.628 to 70.20±0.377. Significantly the highest bread total score (70.20±0.377) was observed for T1 followed by T2 (64.47±0.552) and T3 (59.40±0.684). The lowest bread total score (54.68±0.628) was found in T4. It is also evident from results that the bread total score varied from 60.50±1.924 to 65.04±1.603 among different lines. The highest bread total score (65.04±1.603) was observed in *C. quinoa* V7 followed by *C. quinoa* V9 (61.74±1.651) and *C. quinoa* V2 (61.49±1.842) while the minimum bread total score (60.50±1.924) was observed in *C. quinoa* V2.

The results also showed a significant decreasing trend in bread total score with the increase of quinoa flour in wheat flour. The lines showed a distinctive behavior regarding bread total score as *C. quinoa* V2 and *C. quinoa* V9 has similar effect and *C. quinoa* V1 and *C. quinoa* V7 has distinguished effect. As for as interaction is concerned, all lines showed decreasing trend in the group from T1 to T4. The maximum decreasing trend was observed in *C. quinoa* V2. showed that at 5 %, 10 %, 15 %, and 20 % substitution *C. quinoa* V7 gave better results than other quinoa lines.

### 4.13 Effect of composite flour on textural characteristics of bread

Definite shape, texture and characteristics of bakery products are accepted by the consumers. Any significant variation from its ideal texture characteristic of can resulted in quality decline of product for consumer acceptance. Product texture may also effected by perception of consumer. The significant feature of bread texture include hardness and springiness as well as other characteristic like gumminess, chewiness and cohesiveness.
Table 4.71 Analysis of variance for bread total score

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>173.070**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>1007.840**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>46.600**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>534.110**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>2.140**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.400</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.72 Means for bread total score

<table>
<thead>
<tr>
<th>Treat.</th>
<th>C. quinoa V7</th>
<th>C. quinoa V2</th>
<th>C. quinoa V1</th>
<th>C. quinoa V9</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>72.11±0.443a</td>
<td>69.89±0.310b</td>
<td>69.40±0.516bc</td>
<td>69.42±0.262bc</td>
<td>70.20±0.377a</td>
</tr>
<tr>
<td>T2</td>
<td>67.50±0.361c</td>
<td>63.57±0.318d</td>
<td>63.33±0.504d</td>
<td>63.48±0.289d</td>
<td>64.47±0.552b</td>
</tr>
<tr>
<td>T3</td>
<td>62.50±0.321d</td>
<td>59.28±0.404e</td>
<td>56.27±0.406f</td>
<td>59.57±0.348e</td>
<td>59.40±0.684c</td>
</tr>
<tr>
<td>T4</td>
<td>58.03±0.555ef</td>
<td>53.20±0.153b</td>
<td>53.00±0.265h</td>
<td>54.50±0.361gh</td>
<td>54.68±0.628d</td>
</tr>
<tr>
<td>Means</td>
<td>65.04±1.603a</td>
<td>61.49±1.842b</td>
<td>60.50±1.924c</td>
<td>61.74±1.651b</td>
<td></td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour
T1= 5% quinoa flour + 95% wheat flour
T2= 10% quinoa flour + 90% wheat flour
T3= 15% quinoa flour + 85% wheat flour
T4= 20% quinoa flour + 80% wheat flour
Figure 4.25 Effect of composite flour on bread total score

$T_0 = 0\%$ quinoa flour + $100\%$ wheat flour
$T_1 = 5\%$ quinoa flour + $95\%$ wheat flour
$T_2 = 10\%$ quinoa flour + $90\%$ wheat flour
$T_3 = 15\%$ quinoa flour + $85\%$ wheat flour
$T_4 = 20\%$ quinoa flour + $80\%$ wheat flour
Hardness is defined as the force required for biting bread samples, springiness is the degree to which a sample returns to its original thickness after compression.

4.13.1 Bread hardness

Analysis of variance (Table 4.73) regarding hardness of bread showed that highly significant variation in bread hardness in all experimental measures as compared to control. Exploring the statistical measures further revealed that quinoa lines, treatments have significant effect on bread hardness, however interaction of both quinoa lines and treatments caused significant effect on bread hardness.

It is apparent from the results given in Table 4.74 that bread hardness in different treatments ranged from 344.4±14.12 to 1047.1±23.6. Significantly the highest bread hardness (1047.1±23.60) was observed for treatment T₄ followed by treatment T₃ (778.5±12.12) and T₂ (476.5±08.13). The lowest bread hardness (344.4±14.12) was found in treatment T₁. It is also evident from results that the bread hardness varied from 722.2±81.73 to 616.3±75.2 among different quinoa lines. The highest bread hardness (722.2±81.73) was observed in C. quinoa V2 followed by C. quinoa V9 (668.6±92.03) and C. quinoa V1 (639.5±81.35) while minimum bread hardness (616.3±75.2) was observed in C. quinoa V7.

The results also showed a significant increasing trend in bread hardness with the increase of quinoa flour in wheat flour. The quinoa lines showed a unique behavior regarding bread hardness as all quinoa lines showed distinctively different values of hardness from each other. As for as interaction is concerned all quinoa lines showed increasing trend down the group from T₁ to T₄. Maximum increase was observed in C. quinoa V9. C. quinoa V2 showed best results in T₁ and T₂, while C. quinoa V7 behaved best at T₃ and T₄ which can be viewed from Figure 4.26. The addition of 20% quinoa flour in composite flour produced comparatively harder crumbs when compared to the control (straight grade flour bread) and bread hardness gradually increased at higher replacement levels of flour. The data obtained from the current results are in line with the judgements of Park et al. (2005) who substituted equal to 30% of quinoa flour with flour of wheat, obtained deprived extensible network of gluten that become reason for the hardening of bread crumbs. Similar type of crumb grain and textural profiles have been indicated earlier by means of instrumental and sensorial studies of bread characteristics (Shittu et al., 2007).
Table 4.73 Analysis of variance for bread hardness

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>233223**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>68438**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>25063**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>1188733**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>2415*</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>913</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

* = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.74 Means for bread hardness prepared from composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>C. quinoa V7</th>
<th>C. quinoa V2</th>
<th>C. quinoa V1</th>
<th>C. quinoa V9</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>315.3±2.60</td>
<td>425.0±2.52</td>
<td>318.0±2.65h</td>
<td>319.3±5.49b</td>
<td>344.4±14.12d</td>
</tr>
<tr>
<td>T2</td>
<td>460.0±5.03fg</td>
<td>522.0±3.51f</td>
<td>461.3±4.67fg</td>
<td>463.0±4.16fg</td>
<td>476.5±08.13c</td>
</tr>
<tr>
<td>T3</td>
<td>725.0±4.04e</td>
<td>834.0±4.58d</td>
<td>765.3±6.39de</td>
<td>790.0±5.51de</td>
<td>778.5±12.12b</td>
</tr>
<tr>
<td>T4</td>
<td>965.0±6.08c</td>
<td>1108.0±45.0a</td>
<td>1013.3±12.8bc</td>
<td>1102.3±51.9ab</td>
<td>1047.1±23.6a</td>
</tr>
<tr>
<td>Means</td>
<td>616.3±75.2a</td>
<td>722.2±81.73a</td>
<td>639.5±81.35bc</td>
<td>668.6±92.03b</td>
<td></td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td>506.00±2.31</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T0 = 0% quinoa flour + 100% wheat flour
T1 = 5% quinoa flour + 95% wheat flour
T2 = 10% quinoa flour + 90% wheat flour
T3 = 15% quinoa flour + 85% wheat flour
T4 = 20% quinoa flour + 80% wheat flour
4.13.2 Bread springiness
Analysis of variance (Table 4.75) regarding springiness of bread showed that highly significant variation in bread springiness in all experimental measures as compared to control. Exploring the measures further revealed that quinoa lines, treatments had highly significant effect on springiness and their showed non-significant effect on bread springiness.

It is noticeable from the results given in Table 4.76 that bread springiness in different treatments ranged from 0.980±0.012 to 0.893±0.016. Significantly the highest bread springiness (0.980±0.012) was observed for treatment T1 followed by treatment T2 (0.953±0.012) and T3 (0.925±0.012), while the lowest bread springiness (0.893±0.016) was found in treatment T4. In different treatments T2 showed better results against all quinoa lines (Figure 4.27).

It is also evident from results that the bread springiness varied from 0.882±0.013 to 0.956±0.015 among different quinoa lines. The highest bread springiness (0.963±0.008) was observed in C. quinoa V1 followed by C. quinoa V2 (0.956±0.015) and C. quinoa V9 (0.950±0.014) while minimum bread springiness (0.882±0.013) was observed in C. quinoa V7. The results also showed a significant decreasing trend in bread springiness with the increase of quinoa flour. As for as interaction is concerned all quinoa showed decreasing trend down the group from T1 to T4 while maximum decrease was observed in C. quinoa V2.

4.13.3 Bread cohesiveness
Analysis of variance (Table 4.77) regarding cohesiveness of bread showed that highly significant variation in bread cohesiveness in all experimental measures and significant variation was observed in supplemented bread as compared from control. Exploring the statistical measures further revealed that quinoa lines, treatments had highly significant effect on cohesiveness and interaction of both quinoa lines and treatments caused non-significant variation on bread cohesiveness.

It is observable from the results given in Table 4.78 that bread cohesiveness in different treatments ranged from 0.793±0.010 to 0.848±0.009. Significantly the highest bread cohesiveness (0.848±0.009) was observed for treatment T1 followed by treatment T2 (0.839±0.007) and T3 (0.819±0.008). The lowest bread cohesiveness (0.793±0.010) was found in treatment T4. It is also evident from results that the bread cohesiveness varied from 0.803 to 0.845 among different lines.
### Table 4.75 Analysis of variance for bread springiness

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.00681**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>0.00024 NS</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.01694**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.01685**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.00083 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.00090</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); ** = Highly significant (P<0.01)

### Table 4.76 Means for bread springiness (Lines x Treatment interaction)

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>0.927±0.009</td>
<td>1.020±0.029</td>
</tr>
<tr>
<td>T2</td>
<td>0.903±0.020</td>
<td>0.977±0.003</td>
</tr>
<tr>
<td>T3</td>
<td>0.877±0.003</td>
<td>0.927±0.003</td>
</tr>
<tr>
<td>T4</td>
<td>0.820±0.017</td>
<td>0.900±0.012</td>
</tr>
<tr>
<td>Means</td>
<td>0.882±0.013^b</td>
<td>0.956±0.015^a</td>
</tr>
<tr>
<td>T0</td>
<td>100% Straight grade wheat flour</td>
<td>0.957±0.003</td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T0= 0% quinoa flour + 100 % wheat flour  
T1= 5% quinoa flour + 95% wheat flour  
T2= 10% quinoa flour + 90% wheat flour  
T3= 15% quinoa flour + 85% wheat flour  
T4= 20% quinoa flour + 80% wheat flour
Figure 4.26 Effect of composite flour on bread hardness

Figure 4.27 Effect of composite flour on bread springiness

\( T_0 = 0\% \) quinoa flour + 100 \% wheat flour, \( T_1 = 5\% \) quinoa flour + 95\% wheat flour, \( T_2 = 10\% \) quinoa flour + 90\% wheat flour, \( T_3 = 15\% \) quinoa flour + 85\% wheat flour, \( T_4 = 20\% \) quinoa flour + 80\% wheat flour
The highest bread cohesiveness (0.845±0.013) was observed in *C. quinoa* V9 followed by *C. quinoa* V2 (0.834±0.007) and *C. quinoa* V1 (0.818±0.010) while minimum bread cohesiveness (0.803±0.008) was observed in *C. quinoa* V7 and it can be considered as best quinoa line in all concentration used in this study (Figure 4.28).

The results also showed a significant decreasing trend in bread cohesiveness with the increase of quinoa flour in wheat flour. As for as interaction is concerned all lines showed decreasing trend down the group from T1 to T4.

**4.13.4 Bread chewiness**

Analysis of variance (Table 4.79) regarding chewiness of bread showed that highly significant variation in bread chewiness in all experimental measures as compared from control. Exploring the statistical measures further revealed that quinoa lines, treatments, and their interaction depicted highly significant effect on bread chewiness.

It is apparent from the results given in Table 4.80 that bread chewiness in different treatments ranged from 412.50±13.36 to 867.92±21.95. Significantly the highest bread chewiness (867.92±21.95) was observed for treatment T4 followed by treatment T3 (687.00±24.07) and T2 (479.92±10.77). The lowest bread chewiness (412.50±13.36) was found in treatment T1. It is also evident from results that the bread chewiness varied from 552.58±46.4 to 698.75±59.4 among different lines. The highest bread chewiness (698.75±59.4) was observed in *C. quinoa* V2 followed by *C. quinoa* V1 (623.08±59.7) and *C. quinoa* V9 (572.92±51.1) while minimum bread chewiness (552.58±46.4) was observed in *C. quinoa* V7. As for as interaction is concerned all quinoa showed increasing trend down the group from T1 to T4. Maximum increase was observed in *C. quinoa* V9. Figure 4.29 showed that *C. quinoa* V1 give best results in T1 and *C. quinoa* V7 give best results in T2, T3 and T4 as at this level values of bread chewiness is closer to control than other quinoa lines (Figure 4.29).

**4.14 Biological evaluation of quinoa protein isolates**

Quinoa protein isolates were evaluated for nutritional quality through protein quality bioassay using male Sprague Dawley rats. Rat modeling approach, provided a uniform comparison of test diets containing quinoa protein isolates along with reference diet *i.e.* casein. Diets response growth study integrated protein efficiency ratio (PER), net protein ratio (NPR) and relative net protein ratio (RNPR), whereas nitrogen balance study integrated true digestibility (TD), biological value (BV) and net protein utilization (NPU).
Table 4.77 Analysis of variance for bread cohesiveness

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>0.002**</td>
</tr>
<tr>
<td>Control × Others</td>
<td>1</td>
<td>0.001*</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>0.004**</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>3</td>
<td>0.007**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>0.001 NS</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>0.001</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4.78 Means for bread cohesiveness prepared from composite flour

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T1</td>
<td>0.817±0.015</td>
<td>0.850±0.006</td>
</tr>
<tr>
<td>T2</td>
<td>0.817±0.003</td>
<td>0.843±0.015</td>
</tr>
<tr>
<td>T3</td>
<td>0.800±0.023</td>
<td>0.833±0.015</td>
</tr>
<tr>
<td>T4</td>
<td>0.777±0.003</td>
<td>0.810±0.006</td>
</tr>
<tr>
<td>Means</td>
<td>0.803±0.008b</td>
<td>0.834±0.007a</td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T₀= 0% quinoa flour + 100 % wheat flour
T₁= 5% quinoa flour + 95% wheat flour
T₂= 10% quinoa flour + 90% wheat flour
T₃= 15% quinoa flour + 85% wheat flour
T₄= 20% quinoa flour + 80% wheat flour
Table 4.79 Analysis of variance for bread chewiness

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>16</td>
<td>115210**</td>
</tr>
<tr>
<td>Control x Others</td>
<td>1</td>
<td>126701**</td>
</tr>
<tr>
<td>Lines (L)</td>
<td>3</td>
<td>50825**</td>
</tr>
<tr>
<td>Treatment (T)</td>
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<td>513458**</td>
</tr>
<tr>
<td>L x T</td>
<td>9</td>
<td>2645**</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>82</td>
</tr>
<tr>
<td>Total</td>
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</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

Table 4.80 Bread chewiness prepared from composite flour

<table>
<thead>
<tr>
<th>Treat</th>
<th>Quinoa Lines</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. quinoa V7</td>
<td>C. quinoa V2</td>
</tr>
<tr>
<td>T₀</td>
<td>100% Straight grade wheat flour</td>
<td>400±3.21</td>
</tr>
<tr>
<td></td>
<td>552.58±46.4</td>
<td>698.75±59.4</td>
</tr>
<tr>
<td>T₁</td>
<td>390.00±5.13</td>
<td>487.00±4.36</td>
</tr>
<tr>
<td>T₂</td>
<td>438.33±5.04</td>
<td>534.00±3.06</td>
</tr>
<tr>
<td>T₃</td>
<td>599.67±7.31</td>
<td>809.00±5.29</td>
</tr>
<tr>
<td>T₄</td>
<td>782.33±3.71</td>
<td>965.00±6.66</td>
</tr>
<tr>
<td>Means</td>
<td>552.58±46.4</td>
<td>698.75±59.4</td>
</tr>
</tbody>
</table>

Means showing similar letter are statistically non-significant (P>0.05)

T₀ = 0% quinoa flour + 100 % wheat flour
T₁ = 5% quinoa flour + 95% wheat flour
T₂ = 10% quinoa flour + 90% wheat flour
T₃ = 15% quinoa flour + 85% wheat flour
T₄ = 20% quinoa flour + 80% wheat flour
Figure 4.28 Effect of composite flour on bread cohesiveness

Figure 4.29 Effect of composite flour on bread chewiness

T₀ = 0% quinoa flour + 100% wheat flour, T₁ = 5% quinoa flour + 95% wheat flour, T₂ = 10% quinoa flour + 90% wheat flour, T₃ = 15% quinoa flour + 85% wheat flour, T₄ = 20% quinoa flour + 80% wheat flour
4.14.1 Growth study parameters of experimental diets
Mean squares for growth study parameters comprising protein efficiency ratio and net protein ratio showed significant variations among the rats fed on test diet comparing quinoa protein isolates along with reference diet (Table 4.81).

4.14.2 Protein efficiency ratio
Protein have vital role for the growth and development in addition to providing energy to the body. The analysis of variance (ANOVA) for protein efficiency ratio have been presented in Table 4.81. It is obvious from results that the protein efficiency ratio differed significantly among different quinoa lines. The maximum protein efficiency ratio (3.78±0.05) among the experimental diets was found in *C. quinoa* V7 followed by diet comprised of *C. quinoa* V2 (3.76±0.04). The reference diets including casein had PER value of 3.90±0.04 (Table 4.82). The finding of current study are supported by the findings of Mahoney *et al.* (1975) where it was reported that raw quinoa and cooked quinoa have PER about 2.09 and 2.71 respectively. Protein from diverse origins and their proportions in the formulations can result in variations in the amino acid concentrations, which ultimately alter its efficiency when consumed by individuals (Silva *et al*., 2014). Dijkstra *et al.* (2003) reported that protein efficiency ratio of quinoa is similar to the protein efficiency ratio of casein protein. Results showed that the quinoa protein is of good quality, according to Friedman and Gumbmann (1986) the protein that have PER more than 1.5 is of good quality. The differences in protein efficiency ratio might be due to saponin or bitter substances in quinoa that can cause different in feed intake (Mahoney *et al*., 1975).

4.14.3 Net protein ratio
The analysis of variance for net protein ratio for different quinoa protein indicated that net protein ratio are significantly differed (Table 4.81) among different quinoa lines. The mean values of calcium was observed that after reference casein diet (4.82±0.05) highest value of net protein ratio 4.69±0.05 was found in *C. quinoa* V7 and lowest was observed in *C. quinoa* V1 (3.90±0.04), whilst *C. quinoa* V2 showing 4.62±0.05 and *C. quinoa* V9 illustrated 4.49±0.06 (Table 4.82) net protein ratio.

4.14.4 Nitrogen balance study parameters of experimental diets
Mean squares for true digestibility (TD), biological value (BV) and net protein utilization (NPU) demonstrated significant variations among the tested diets along with control diet presented in Table 4.82.
### Table 4.81 Mean square for biological evaluation of quinoa protein isolate

<table>
<thead>
<tr>
<th>SOV</th>
<th>DF</th>
<th>PER</th>
<th>NPR</th>
<th>TD</th>
<th>NPU</th>
<th>BV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diet</td>
<td>4</td>
<td>0.18737**</td>
<td>0.64370**</td>
<td>123.017**</td>
<td>510.087**</td>
<td>135.017**</td>
</tr>
<tr>
<td>Error</td>
<td>20</td>
<td>0.01291</td>
<td>0.01577</td>
<td>4.778</td>
<td>4.521</td>
<td>5.549</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** = Highly significant (P<0.01)

### Table 4.82 Means for biological evaluation of quinoa protein isolate

<table>
<thead>
<tr>
<th>Diet</th>
<th>PER</th>
<th>NPR</th>
<th>TD</th>
<th>NPU</th>
<th>BV</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. quinoa V7</td>
<td>3.50±0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.69±0.05&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>90.57±1.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>73.78±0.89&lt;sup&gt;b&lt;/sup&gt;</td>
<td>81.74±0.99&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. quinoa V2</td>
<td>3.76±0.04&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.62±0.05&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>89.43±1.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>71.13±0.86&lt;sup&gt;b&lt;/sup&gt;</td>
<td>80.70±0.98&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. quinoa V1</td>
<td>3.45±0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.90±0.04&lt;sup&gt;c&lt;/sup&gt;</td>
<td>87.66±1.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>70.75±0.86&lt;sup&gt;b&lt;/sup&gt;</td>
<td>79.15±0.96&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. quinoa V9</td>
<td>3.78±0.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.49±0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>88.94±1.13&lt;sup&gt;b&lt;/sup&gt;</td>
<td>71.34±0.98&lt;sup&gt;b&lt;/sup&gt;</td>
<td>80.64±1.21&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Casein</td>
<td>3.90±0.04&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.82±0.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>99.99±0.91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94.18±1.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>91.99±1.11&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means with similar letter are statistically non-significant (P>0.05)

PER=Protein efficiency ratio, NPR= Net protein ratio, TD= True digestibility, BV=Biological value

NPU=Net protein utilization
4.14.5 True digestibility

True protein digestibility is measured by dried rat bodies, feed intake, urinary and fecal nitrogen. Among the tested diets maximum digestibility (90.57±1.10%) was observed in *C. quinoa* V9 protein isolates, followed by *C. quinoa* V2 (89.43±1.08%). However, diet containing casein showed true digestibility of 99.99±0.91% (Table 4.82). Better digestibility of *C. quinoa* V9 protein isolates signified lower fecal nitrogen output and higher retention in rat bodies. The minimum true digestibility in *C. quinoa* V1 fed animals was might be due to lower consumption of diet. The findings of current research supported by Dijkstra *et al.* (2003) who reported that quinoa protein have 84% true digestibility.

4.14.6 Biological value (BV)

Biological value is a measurement of nitrogen kept for maintenance or growth of optimal health. Means for the effect of feeding diets containing quinoa on Sprague Dawley rats (Table 4.82) exhibited highest biological value of *C. quinoa* V9 (81.74±0.99%), followed by *C. quinoa* V2 (80.70±0.98%). However, rats fed on casein based diets exhibited 91.99±1.11% BV. It was reported that quinoa have 43-51% biological value Dijkstra *et al.* (2003).

4.14.7 Net protein utilization (NPU)

Means for the effect of quinoa protein isolates on Sprague Dawley rats showed (Table 4.82) that *C. quinoa* V9 have better net protein utilization (73.78±0.89%). The lowest NPU was observed in *C. quinoa* V1 *i.e.* 70.75±0.86%. However, the means for NPU were 94.18±1.14% for casein diet. The results of current findings are in line with the findings of Guzman-Maldonado and Paredes-Lopez (1998) who reported that quinoa have 76% NPU.
Malnutrition deficiencies has gained massive attention in novel dietary strategies owing to their affirmative influence on normal body functioning. Presently in the developing countries like Pakistan, deficiencies of nutrient, minerals, protein are prevailing due to inadequate dietary intake and poor nutritional practices. Many interventions such as food fortification, dietary supplementation, diet diversification, and diet modifications are in practice to alleviate nutritional disorders.

The current project is an effort to probe the nutritional worth of quinoa and its utilization in food products. For the purpose, quinoa line grown in Pakistan were evaluated for their physicochemical attributes, mineral profile, fatty acid profile, thermal properties, pasting properties and In-vitro digestion of quinoa starch and protein. Moreover, quinoa protein isolates were extracted & evaluated for their functional properties whilst the effects of quinoa flour substitution on dough rheology and bread quality were also investigated. Bread prepared with the addition of quinoa flour were assessed for different textural & sensorial attributes. Furthermore, biological evaluation of quinoa protein was assessed by growth parameter (protein efficiency ratio, net protein ratio and relative net protein ratio and nitrogen balance study (true digestibility, biological value, and net protein utilization) using Sprague Dawley rats. At the end, statistical analysis for each parameter was carried out by using experimental designs.

Results of current research showed that moisture of quinoa ranged from 9.74±0.22 to 10.62±0.24%, crude ash ranged from 2.18±0.08 to 2.80±0.02%, crude protein ranged from 11.00±0.34 to 16.08±0.02, crude fat ranged from 3.57±0.11 to 7.97±0.12%, crude fiber ranged from 1.99±0.12 to 3.52±0.18% and total ash ranged from 53.43±0.23 to 63.15±0.92%. Quinoa seeds are also rich in mineral nutrients. It can be summarized that calcium, magnesium, manganese, sodium, sulphur, phosphorous, zinc, boron, and copper ranged from 8497.08±51.97 to 9443.41±114.7, 578.35±4.53 to 669.45±5.20, 30.66±0.21 to 35.28±0.12, 24.58±0.29 to 62.81±0.52, 24.58±0.29 to 62.81±0.52, 1499.21±9.30 to 1606.30±8.29, 4491.6±20.78 to 4560.0±16.16, 24.30±0.22 to 32.12±0.52, 15.29±0.05 to 17.04±0.07 and 4.01±0.02 to 5.04±0.06 mgkg⁻¹, respectively.

Due to higher nutritional value of Quinoa, it has great potential for improving food for humans. Quinoa was also characterized for fatty acid (FA) composition. FA pattern in the seed was characterised by: palmitic acid (C16:0), oleic acid (C18:1 n-9), linoleic acid
(C18:2 n-6), α-linolenic acid (18:3 n-3) and erucic acid result showed that Palmitic acid ranged from 11.39±0.02 to 13.25±0.30%, oleic acid from 26.28±0.15 to 31.62±0.14%, linoleic acid ranged from 47.79±0.19 to 52.02±0.54%, α-linolenic acid ranged from 4.45±0.03 to 7.71±0.06% and erucic acid 1.41±0.01 to 1.74±0.00%.

The physicochemical characteristics i.e. thermal and pasting properties of four quinoa lines were compared. The gelatinization onset and peak temperatures and end temperature differed highly significantly among quinoa starches and flour. The gelatinization enthalpies also differed highly significantly. The onset temperature ranged from 53.90±0.24 to 62.78±0.10oC, peak temperature ranged from 60.75±0.59 to 68.26±0.03 and end temperature ranged from 64.82±0.19 to 74.61±0.06oC. The gelatinization enthalpy for quinoa flour and dry starch was ranged 3.03±0.19 to 7.11±0.24 and 5.79±0.44 to 12.97±0.44 J g⁻¹ respectively. Moreover, rapid visco analyzer was used to determine the pasting properties the results showed that setback viscosity, peak time, peak temperature, peak viscosity, trough viscosity, breakdown viscosity, and final viscosity ranged from 346.0±30.51 to 113.3±04.67RVU, 6.97±0.02 to 6.99±0.01min., 62.18±1.02 to 74.28±0.96°C, 232.0±11.37 to 374.3±12.17RVU, 198.0±9.54 to 301.7±5.81, 34.00±2.52 to 72.67±6.44RVU and 311.3±10.40 to 580.7±45.80RVU respectively.

Furthermore quinoa protein isolated were prepared to determine its functional properties i.e. water absorption capacity, oil absorption capacity, emulsion capacity, and foaming capacity. Results showed that water absorption capacity ranged from 2.81±0.17 to 3.82±0.05%, oil absorption capacity ranged from 2.72±0.2 to 3.03±0.03%, emulsion capacity ranged from 102.00±0.71 to 106.53±1.33% and foaming capacity ranged from 7.74±0.09 to 10.05±0.07%. The in vitro digestibility of protein and starch in raw quinoa assessed by an enzymic method. In-vitro starch and protein digestion showed that quinoa starch digestibility ranged from 79.41±0.55 to 91.29±6.7% and protein digestibility ranged from 75.95±0.29 to 78.11±0.43%. However, dough rheological properties and baking performance depend on the sort and quality of basic cereal used, and the baking quality of quinoa containing composite flour could also be improved by common used bread-making additives. Another fact limiting composite bread acceptance is a distinct aroma and flavor of quinoa grain. Deteriorative sensory effects occurred at higher substitution rates.

However, consumer’s food acceptance depends on sensory, but also on non-sensory factors. The non-sensory factors include not only aspects such as convenience and price of preparation, but also the consumer’s attitudes, production methods, awareness of health and
the environment, and product beliefs.

The replacement of wheat flour at different levels (from 0 up to 20%) by quinoa flour revealed different physicochemical properties and breads with variable sensory acceptability and depending on both the degree of wheat flour and quinoa flour substitution. Replacement of wheat flour by up to 20% led to different colored breads with acceptable sensory perception coming from doughs with acceptable thermo-mechanical patterns. Addition of quinoa flours to wheat flours constitutes a viable substitute to enhance the nutritional value of breads in terms of qualitative and quantitative protein composition. Quinoa integral flour addition to wheat flour weakens the ability at latter stage for making dough. The sample with 20% of quinoa flour shows inappropriate values for making bread as indicated by farinogram parameters.

Nutritional composition elucidated the potential characteristics of quinoa seeds as most valuable components for bread production to enhanced nutritional characteristics. The results described the possibility of valuable product with higher nutritious value along with acceptable sensory properties. The nutritive worth of supplemented breads with seed mixture was improved higher fiber and protein content. Modification of technological procedure of seed preparation afforded the inclusion of such high levels of seed in bread and could enable for the development of extensive variety of bakery products with improved nutritious value.

The growth responses (cumulative bodyweight gain) obtained during the PER there was significant difference in weight gain of the rats fed quinoa or casein. This could be the reason for the small, but significant, difference observed in protein digestibility between quinoa and casein. Apparent protein digestibility is based on fecal protein losses. The simultaneous consideration of urinary protein losses (as nitrogenous end products) provided a more precise estimate of protein quality and revealed that urinary nitrogen losses were lower in rats fed quinoa. The quality of protein in quinoa equals that of casein.

Quinoa has great potential to provide diverse and the nutritious food in developing countries and other regions of the world. These crops maintained excellent guarantee to the rural agroindustry for producing natural, healthy, and highly nutritive products that are beneficial for the producer and consumer.

In Pakistan, the production of the rich variety of quinoa seeds differed in their nutritional properties, protein, fat, minerals, ash content, and nutritional value. But all quinoa lines showed excellent nutritional quality. For genetic improvement trails and creation of new
and better varieties, nutritional aspects of quinoa seeds offer significant opportunities to resolve the problem of crop adaptation to climate and soil conditions are limiting for other crops, where hunger is still an unsolved problem. This may contribute to the origin of the commercial value of the Pakistani quinoa in national and international markets. In order to get extra benefits, the consumers would definitely prefer to pay extra. Comparatively Quinoa has higher nutritive components like minerals, protein and vitamins than wheat, which will attract the consumers. Quinoa appears as a good option that fulfills almost all nutritional requirements while providing moieties with health-promoting properties.
CONCLUSIONS

- Quinoa has higher nutritional profile *i.e.* fatty acids, protein, carbohydrate, and minerals
- Quinoa also effect the textural attributes and sensorial characteristics of bread while increasing trend were obtained regarding product chemical composition
- Due to inherent capacity of non-development of gluten, it can be used as potential candidature for celiac patients
- Higher emulsifying capacity of quinoa protein isolates can be useful for food applications
- *In vitro* and *in vivo* digestion showed that quinoa possessed high quality protein
- In the nutshell, quinoa holds potential to be utilized in food products for best quality and value addition
Recommendations

- Quinoa and its protein isolates should be utilized for the production of value added products
- Should be explored for complete nutritional profile *i.e.* Amino acids, Phenolic, Antioxidants, Flavonoids
- Quinoa saponin needs to be researched for nutraceutical worth as vulnerable segments
Future Research Directions

Worldwide quinoa has gained importance owning to its tremendous nutritional properties. It is therefore important for nutritionists and health professionals to take interests in plants and their products for their multifarious functionalities. High nutritional value and gluten free properties makes it a great choice for those peoples who are suffering from digestive problems of gluten making a prodigious opportunity for a producing wide range of new food products.

Extrusion cooking of quinoa will continue to be explored in future research. Extrusion procedure is extremely useful and malleable to an extensive selection of applications and possibly will provide new inimitable ways of producing pseudo-cereal foodstuffs.

Future research must emphasis on the depiction and utilization of its saponins for the purpose of their medical application like anti-inflammatory mediators and coadjutants in the fascination of certain medicines, given their capability to prompt changes in permeability of intestine. It has been reported that triterpenes present in quinoa have low toxicity. The low toxicity of these natural compounds reflect that these could work as a natural source of new rudiments for the development of medicines.

Future research should be directed to detect relations between obesity or overweight, possible signs of diabetes, and regularity in the consumption of grain. Keeping in view that is consumed by studying members as well as the quantity (i.e., portion size) consumed at each meal. This study will deliver insights concerning differences in insulenic and glycemic responses. It will also permit for the observation of the point of influences upon such responses which can be attributed to such factors as method of cooking and its temperature along with the use of other components that can impact on such responses.
Limitations of Present Study

Much research work should be focused on nutritional comparison of quinoa in relation to other cereal crops rather than its health benefits.

During the trial, chemical were used for the extraction of protein isolates which might be fatal or toxic for human beings so I recommended only aqueous method should be used for extraction of protein isolates.

In current situation much attention has not given to research work due to unavailability of sources and energy crisis, so Government should focus on uplift of energy for better understanding of research.
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### (Appendix I)

#### BREAD EVALUATION PERFORMA

<table>
<thead>
<tr>
<th>EXTERNAL</th>
<th>Perfect Score</th>
<th>Sample Score</th>
<th>PENALIZED FOR:-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>10</td>
<td>Too Small</td>
<td>Streaked</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Too Large</td>
<td></td>
</tr>
<tr>
<td>Color of Crust</td>
<td>8</td>
<td>Not Uniform</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dark Dull</td>
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</tr>
<tr>
<td>Symmetry of Form</td>
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<td>Low End</td>
<td>Low Side</td>
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<tr>
<td></td>
<td></td>
<td>Promuding Crust</td>
<td>Low Middle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uneven Top</td>
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<td></td>
<td></td>
<td>Shrunk Side</td>
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<tr>
<td>Evenness of Bake</td>
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<td>Light Bottom</td>
<td>Small End</td>
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<td></td>
<td></td>
<td>Dark Bottom</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Spotty” Bottom</td>
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</tr>
<tr>
<td>Character of Crust</td>
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<td>Thick</td>
<td>Insufficient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tough</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brittle</td>
<td></td>
</tr>
<tr>
<td>Break and Shred</td>
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<td>One Side Only</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wild Break</td>
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<td></td>
<td>No Shred</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shell</td>
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</tr>
<tr>
<td>INTERNAL</td>
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<td>Open Coarse</td>
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<td></td>
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<td>Non-Uniform</td>
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<td></td>
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<td>Thick Cell Wall</td>
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<tr>
<td></td>
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<td>Holes</td>
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<td>Grain</td>
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</tr>
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<td>Dull</td>
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<td>Strong</td>
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<td>Lack of</td>
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<tr>
<td></td>
<td></td>
<td>Unpleasant After taste</td>
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<td></td>
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<tr>
<td></td>
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<td>Tough</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Gummy</td>
<td></td>
</tr>
<tr>
<td>Texture</td>
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<td>Rough-Harsh</td>
<td>Ridged</td>
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<td>Lumpy</td>
<td>Too loose</td>
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<td></td>
<td></td>
<td>Core</td>
<td>Too Compact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crumbly</td>
<td></td>
</tr>
</tbody>
</table>

| Total Score       | 70            |                           |                                     |
|                   | 100           |                           |                                     |

(Matz, 1960)
(Appendix II)

Explanation of Score

External Characteristics

Volume
The desired volume varies different sections of the country. Nevertheless, in order to render an unbiased value for volume on the enclosed score, standards for white pan bread have been established. These standards are given below.

<table>
<thead>
<tr>
<th>Cubic Inches per Oz.</th>
<th>Value on Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.5 to 12.4</td>
<td>9.0</td>
</tr>
<tr>
<td>10.5 to 11.4</td>
<td>9.5</td>
</tr>
<tr>
<td>9.5 to 10.4</td>
<td>10.0</td>
</tr>
<tr>
<td>8.5 to 9.4</td>
<td>9.5</td>
</tr>
<tr>
<td>7.5 to 8.4</td>
<td>9.0</td>
</tr>
<tr>
<td>6.5 to 7.4</td>
<td>8.5</td>
</tr>
<tr>
<td>5.5 to 6.4</td>
<td>8.0</td>
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</tbody>
</table>

Color of Crust
The color of crust should be an appetizing nut-brown. It should be uniform, free from spots or streaks. The crust may or may not have a glaze depending on the requirements of various localities.

Symmetry of Form
The loaf should be symmetrical without low ends or overlapping.

Evenness of Bake
The loaf should be evenly baked on all sides including the bottom. It should be evenly colored with no light or burned spots. The shade of the sides and bottom should conform with that of the crust.

Character of Crust
A good crust is thin and breaks easily. It should not be thick, tough, or rubbery.

Break and Shred
The loaf should have a uniform, smooth break, with a well-defined shred on all sides. A ragged break or a shell crust detracts from the appearance of the loaf.

Internal Characteristics

Grain
The grain is the structure formed by the strands of gluten, including the area they surround. The cell structure varies considerably with the different types of bread, for example, cross pan, the twist or the regular round top loaf and no standard can be established. In every case the structure should be uniform with thin-walled cells.

Color of Crumb
No definite tint can be established for the color of crumb. However, it should be bright with some luster. The surface should present a uniform shade without streaks or dark patches.

Aroma
Aroma as here used is recognized by the organs of smell. The aroma may be noted as sweet, rich, fresh, nutty, husky, metallic, flat, or sour. The ideal loaf has a pleasant, wheaty, and nutty aroma.

Taste
The most important attribute of good bread is that it has a pleasant and satisfying wheaty taste.

Mastication
Mastication as used here is solely to judge chewing qualities of the loaf. The ideal loaf should be free from dryness and should not be dry or tough.

Texture
Texture is determined by the sense of touch. It depends on the physical condition of the crumb and is influenced by the grain. It is an expression of the pliability and smoothness of the crumb. The ideal texture is soft and velvety, without weakness, and should not crumble.

(Matz, 1960)