ABSTRACT

*Chenopodium quinoa* seeds possess higher nutritional value and are an excellent source of bioactive components in comparison to traditional cereals. Increase in demand of robust, high nutritional value, gluten free crops and products have skyrocketed due to increase in incidence of food insecurity, malnutrition and celiac disease. Quinoa due to its rusticity, wide adaptability, high nutritional profile and gluten free nature can be considered as a healthy and safe alternative. Further, the seeds contain small granule size starch which calls for its commercial exploration. The present study was undertaken for characterisation, processing and utilization of quinoa (*Chenopodium quinoa willd.*) seeds. Germplasms of two *C. quinoa* varieties were obtained from the National Bureau of Plant Genetic Resources (NBPGR) Shimla and cultivated at the experimental farm of campus. The investigation was compiled into five chapters. Chapter one is the introductory part and includes the description, origin, nutritional value, antinutritional components, processing and potential of the crop for food security and malnutrition. Last section of the chapter one includes the objectives of the present research work. Chapter two deals with the literature review on production, harvesting, physical properties, grinding of seed and characterization of flour, starch isolation and modification. Literature regarding physico-chemical, structural and thermal characteristics of native and modified starches, processing and utilization of quinoa flour and starch is also present in this chapter. Further, the literature regarding packaging, storage stability and *in vitro* digestibility of products is also present in chapter two. Chapter three provides the detailed information regarding the materials and methods used throughout the research work. This chapter includes the materials used and methodology followed for characterisation of seed, flour, starch and their conversion to products followed by *in vitro* digestibility of developed products. Chapter four included the results and discussion of the present
investigation in line with the methods described in chapter three. Chapter four was further divided into various sections as per the objectives of the study.

The first section of chapter four included the effect of moisture content on various physical properties of *C. quinoa* seed. Engineering properties at different moisture contents are required to design machines and storage facilities. For grains there is a notable increase of pressure on silo walls due to increased moisture content. Close dependency of the physical properties (except sphericity) on moisture content was observed. The results showed that with increase in moisture content from 5 to 25% arithmetic mean diameter varied from 1.47 to 1.71 mm for *C. quinoa* V1 and from 1.58 to 1.80 mm for *C. quinoa* V2. Mean values of true density increased from 993 to 1166 kg/m$^3$ for V2 and from 984 to 1097 kg/m$^3$ for V1 with increase in moisture content. V2 showed higher values of bulk density and coefficient of friction. With increase in moisture content coefficient of friction showed an increase of 16.29, 16.00, and 18.93% against glass, galvanised iron and wood respectively in case of V2. However, for V1 increase of 19.12, 22.73, and 23.21% was observed against glass, galvanised iron and wood respectively.

The 2nd section of chapter four consisted of grinding of quinoa seeds using two mills (stone mill and cyclotec mill) for preparation of flour. Flour thus obtained was analysed for particle size distribution, color and functional properties for the selection of suitable mill. Average particle size for V1 was found to be 0.274 mm for stone mill and 0.243 mm for cyclotec mill. However, in case of V2 average particle size was found to be 0.254 mm for stone mill and 0.221 mm for cyclotec mill. Among both the mills cyclotec mill showed the ability to produce more uniform and finer flour with better functionality. Hence, cyclotec mill was selected for preparation of flour from *C. quinoa* seeds.

Characterization of the quinoa flour in terms of various physicochemical, functional, pasting, morphological and structural properties was discussed in 3rd section of chapter four.
This section also included the determination of mineral composition, fatty acid profile, dietary fibre content, antioxidant properties and effect of treatments on anti-nutritional constituents of quinoa. Quinoa flour from both the varieties showed typical A-type diffraction pattern. V1 showed higher starch content and pasting profile while as V2 showed higher protein, dietary fiber and antioxidant properties. Total phenolic content was found to be 196.59 mg GAE/100g for V1 and 218.37 mg GAE/100g for V2. Soaking along with rubbing was found to be more effective for removal of antinutritional components in comparison to soaking alone.

In 4\textsuperscript{th} section of chapter four process standardisation for isolation of starch and its characterisation was discussed. For standardisation of starch isolation process quinoa seed was soaked in alkali in two forms (ground and whole). Also the alkali concentration was varied from 0.20-0.30% w/v. Soaking of \textit{C.quinoa} in the ground form resulted in higher starch yield for both the varieties. Increase in alkali concentration upto 0.25% increased the starch yield and purity. However, further increase in alkali concentration to 0.30% decreased the yield. Soaking of seed in ground form at an alkali concentration of 0.25% were selected as the standard conditions for isolation of starch from \textit{C.quinoa}. Amylose content was found to vary from 9.46\% for V2 to 12.10\% for V1. L-value was found to be higher for V1 (97.27) than V2 (96.80). Swelling power and solubility of both the starches increased with increase in temperature and attained the maximum value at 95 °C. Turbidity of starch gel increased with increase in duration of storage and was higher for V1 than V2. Scanning electron microscopy revealed the presence of irregular, angular and polygonal shape starch granules with almost smooth surfaces for both the varieties. Both the starches showed A- type diffraction pattern as observed by X-ray diffraction analysis. Fourier transform infrared spectroscopic analysis of quinoa starches revealed the presence of almost similar structural components with V2 showing the higher intensity and broader shape of peaks.
In 5th section of the chapter four process optimization for preparation of product from *C. quinoa* flour and quality characteristics of optimized product have been discussed. *C. quinoa* V2 due to its smaller particle size, higher protein, dietary fiber, functional and antioxidant properties was used for development of flour based product (cookies). Optimization of processing conditions for development of cookies was done by using central composite rotatable design (CCRD) of response surface methodology. Variables for the process included sugar, fat, temperature and time. The levels of these variables were varied to determine their effect on responses (color, spread factor, hardness, antioxidant activity and overall acceptability) defining consumer acceptance of cookies. Results obtained from this study validate the production of functional and acceptable gluten-free cookies made from whole quinoa flour. Analysis revealed that the selected independent process variables had a dominant effect on responses. Increase in fat and sugar content increased spread factor and decreased the hardness of cookies, while an increase in baking temperature and time decreased spread factor and increased hardness.

6th section of the chapter four includes optimization of process for preparation of *C. quinoa* starch based product (noodles) and its quality characteristics. Demand for starch noodles is increasing worldwide and the limited output from commercial sources is unable to meet the needs. Starch noodles were prepared from native as well as modified starches to observe the effect of modification on starch properties as well as noodle quality. Two types of modifications (heat moisture treatment and gum addition) were used. Modifications successfully improved the properties of the starch as well as the noodle quality with addition of hydrocolloid being more desirable than HMT. Both the modifications decreased the cooking loss from 7.18 g/100g in case of native to 6.17 g/100g and 5.25 g/100g in case of HMT starch noodles and gum modified noodles respectively. Among all the samples gum
added quinoa starch resulted in the noodle sample with best cooking, textural and sensory characteristics.

Storage study of developed products has been discussed in section 7th of chapter four. Optimized cookies prepared from quinoa were stored in two different packaging materials (LDPE and MET-PPE) under the atmospheric conditions of 30±2 °C temperature and 65±5% relative humidity. Results revealed that quality characteristics of the cookies packed in MET-PPE were acceptable and within permissible limits upto 120 days. Optimized noodles from starch were stored in two different packaging materials (LDPE and BOPP) for 180 days at a temperature and relative humidity of 30±2 °C and 65±5% respectively. Stored packed samples were then withdrawn periodically every 30 days for analysis of various quality characteristics. All the desirable attributes showed decline throughout the storage study with the decline being more prominent in case of sample packed in LDPE. Overall analysis revealed that the samples packed in both the packages were acceptable and within permissible limits upto 180 days.

Optimized products were then studied for in vitro protein and starch digestibility. To determine the in vitro digestibility of the optimized products, flour and starch from the same variety was taken for comparison purpose. Developed flour based product showed higher in vitro protein digestibility than the corresponding flour. As the noodles were prepared from starch and is devoid of protein the protein digestibility of noodles was not studied. Protein digestibility results revealed that the processing conditions like baking can improve the protein digestibility of the food due to unfolding of protein at higher temperatures. Product (noodles) developed from starch showed lower in vitro starch digestibility than that of the starch from which it was developed. While as, the product developed from flour (cookies) showed slightly higher in vitro starch digestibility in comparison to the flour from which it was developed.