SUMMARY
&
CONCLUSIONS
5. SUMMARY AND CONCLUSIONS

5.1: Studies on Finger Millet varieties

5.1.1. Three hilly varieties grown at 5500 ft asl and seven base varieties grown at 2300 ft asl, were evaluated for their characteristics.

5.1.2. In finger millet varieties, the visual colour ranged from light brown to dark brown and to cream white. Puffing yield was higher in base varieties when compared to hilly varieties. MR-1 and Indaf-11 varieties had highest puffing yield.

5.1.3. In finger millet varieties, the image analysis of the grains showed that the total grain count of puffed samples reduced to half the value of native grains and the varieties had the influence on the total grain count.

5.1.3. In finger millet starch from different varieties, the relative flatness of particle, degree of deviation from symmetry showed higher value in native starch particles as compared to puffed samples, may be due to gelatinisation of starch during puffing.

5.1.4. In finger millet varieties, total sugars ranged from 3.1 to 4.4%. During puffing, reducing and total sugars reduced by 19% and 12.5% respectively, which can be attributed to non-enzymatic browning reactions during puffing.

5.1.5. In finger millet varieties, the average starch content of hilly and base varieties was 74.6 ± 4%. During puffing, the starch content was reduced by 2% in hilly samples and 4% in base varieties.

5.1.6. The amylose content ranged between 15.6 and 16.3% in native flour samples while in puffed samples it ranged between 15.3 to 16.0%. It is concluded that there was not much difference between hilly and base varieties as well as the puffing of finger millet on the amylose content.
5.2: Studies on Starch Fractions of Finger Millet

5.2.1. The finger millet starch was having 10.85% moisture, 1.86% protein, 1.00% fat, 1.5% ash and 20.25% amylose.

5.2.2. In finger millet varieties, readily digestible starch was 9.27 to 9.95% and slowly digestible starch was 28.0 to 30.56% and total available starch was 40.31 to 47.81%. Relatively the hilly varieties had higher levels of all the three fractions than base varieties.

5.2.3. Puffing of finger millet varieties resulted in an increase of readily digestible starch by 9.61 to 16.08% and decrease in slowly digestible starch by 32.24%. These changes were higher in hilly varieties as compared to base varieties.

5.2.4. The method of determination of resistant starch was suitably modified for finger millet samples by modifying amylglucosidase concentration and the incubation time as compared to Goni et al (1996) procedure. In finger millet varieties, the resistant starch ranged from 0.7 to 0.85% and 0.78 to 0.99% in hilly and the base varieties respectively.

5.2.5. Relatively hilly varieties had lower resistant starch than those in base varieties and on an average 0.85% was present in ragi. Puffing of finger millet reduced the resistant starch by 19.65%.

5.2.6. Statistical analysis of the data revealed that the changes in starch fractions among the native and puffed finger millet varieties were not significant (p<0.5) except for the RS fraction. However, the changes between resistant starch and slowly digestible starch were significant (p<0.5).

5.2.7. Statistical analysis of the data amongst the starch fractions revealed that the readily digestible starch and slowly digestible starch were negatively correlated with resistant starch in both native and puffed samples.
5.2.8. The data on starch fractions in hilly and base region varieties and effect of puffing on finger millet have been reported for the first time.

5.3: Functional Properties of Finger Millet Flour

5.3.1. The water absorption capacity of hilly varieties was higher than that of base ones ranging from 1.48 to 1.59 g/g and 1.21 to 1.45 g/g respectively

5.3.2. Puffing increased the Water absorption capacity by 1.5 times as compared to native ragi samples, while Fat absorption capacity remained almost same among the varieties ranged between 0.92 to 1.19 g/g.

5.3.3. In finger millet varieties, 24 to 34% gelatinization was observed in native flours during milling, while puffing resulted in 70-99% gelatinisation.

5.3.4. In finger millet varieties, the starch digestibility in native flour being 7 to 9% increased to 29 to 35% during puffing

5.3.5. In finger millet varieties, the dietary fiber ranged from 14.88 to 19.22% as insoluble fiber and 0.61 to 0.79% as soluble fiber with an increase of 2-3% of total dietary fiber during puffing.

5.3.6. Statistical analysis of the data on dietary fiber of finger millet varieties revealed that the changes were significant among native finger millet varieties as well as the changes in dietary fiber between native and puffed flour samples (p<0.05).

5.3.7. In finger millet starch varieties the gelatinization temperature ranged between 72.6 to 76.1°C as studied by visco-amylograph. It was not influenced by region of cultivar, however, for VL-146, Indaf-5 and HR-911 relatively higher gelatinisation temperature was observed i.e. 79.3°C, 81.7°C and 80.9°C respectively.
5.3.8. In finger millet starch, the peak viscosity for hilly varieties was 354 to 391 Bu, while for base varieties it was 350 to 422 Bu, reflecting that some of the base varieties have greater water binding capacity.

5.3.9. In finger millet starch varieties, the onset, peak and conclusion temperature for hilly varieties by differential scanning calorimetry ranged from 57.3 to 62.7°C, 60.7 to 67.1°C and 71.5 to 77.2°C respectively, while in base varieties, it was 52 to 68.4°C, 55.9 to 76.8°C and 69 to 89.7°C respectively showing that the temperature for melting of starch granule crystallites differ with varieties.

5.3.10. The enthalpy value (ΔH) was found to be lower for hilly varieties 19.3 to 20.85 J/g as compared to base samples 20.1 to 29.6 J/g and the span of endotherm was sharp for hilly varieties 14.2 to 15.1°C which in base varieties ranged from 10.9 to 28.1°C.

5.3.11. The gelatinization endotherms by differential scanning calorimetry were absent in puffed varieties, which attributed to gelatinisation of starch during puffing.

5.3.12. The average percent crystallinity in hilly and base varieties was 48.37 and 46.77% in native flour while 55.64 and 56.03% in puffed finger millet samples. The percent crystallinity during puffing increased from 49.02 to 62.85%.

5.3.13. The decomposition temperature in finger millet MR-1 variety as measured by Thermogravimetric analysis. The first step transition in native dry starch 8.29% was lower as compared to puffed sample 8.70%.

5.3.14. In wet puffed starch, the first transition was very large showing 80% followed by 12% in second transition.
5.4: Effect of Processing on Starch Components of Finger Millet

5.4.1. In standardized system of processing, the readily digestible starch content increased to 23% during pressure cooking, 16% after cooking and autoclaving, 10% during puffing and malting, while baking, frying and toasting reduced the readily digestible starch content.

5.4.2. In standardized system of processing, the slowly digestible starch content was found to be reduced by 4 to 8% during baking, frying, germination and malting while in other methods such as cooking, pressure cooking, autoclaving, re-autoclaving, roasting, toasting (dosa and roti) and puffing it reduced by 14 to 24%.

5.4.3. In standardized system of processing, the resistant starch content ranged from 0.27% to 3.08%, lowest in case of frying and highest in the case of roasting. The resistant starch content decreased with the majority of the processing methods, while increased resistant starch was recorded during cooking and roasting.

5.4.4. In standardized system of processing of finger millet flour, the percent gelatinization was found to be highest during puffing by 97% followed by 89.18% for pressure cooking, 65.38% for autoclaving; 56.32% for cooking and 53.33% for repeated autoclaving, while in rest of the methods it was less than 25%.

5.4.5. In standardized system of processing of finger millet flour, the starch digestibility increased to about 35 to 40% during cooking, autoclaving and pressure cooking while it was 25% for germination and 10 to 12% for other processing methods such as frying, toasting, malting, baking and roasting.

5.4.6. In standardized system of processing of finger millet flour, cooking methods resulted in relatively higher dietary fiber content. The insoluble fraction was found to be highest in
cooking 12.97% and lowest in baking 8.55%, whereas, soluble fiber was highest in malting 3.25% and lowest during puffing 0.76%.

5.4.7. In convenience mixes, the starch digestibility was found to be higher in sweetened millet mix 32.88 mg/g, spiced millet mix 38.05 mg/g and beverage mix 40.45 mg/g where puffed ragi flour was the major ingredient.

5.4.8. The resistant starch, a functional fiber was found to be highest in sweetened millet mix 2.4% and lowest in millet roti 0.60%.

5.5: Development of Millet based Products, their Stability and Properties

5.5.1. Finger millet based products such as millet halbai mix, millet snack mix, millet pasta and millet enteral feed were developed using response surface methodology with a statistical software stat-ease.

5.5.2. All the finger millet based products had the overall acceptability score from 7.7 to 8.5 on 9 point hedonic scale.

5.5.3. In finger millet based products, the protein content ranged from 7 to 34.5%, lowest for halbai mix and highest for enteral feed.

5.5.4. The carbohydrate profile in finger millet based products showed that the readily digestible starch was found to be maximum in pasta, an extruded product 14.4% and minimum in fried snack, a dry mix 5.30% slowly digestible starch was recorded as 21.02 to 30.78% for enteral feed and halbai mix respectively.

5.5.5. In finger millet based products, the major fatty acids were 35-44% palmitic, and 41-52% linoleic acid. In halbai mix the major fatty acid was lauric acid 18.4%, while lauric acid was found be minimum in fried snack mix i.e. 1.70%. However, the fatty acid profile is based on the ingredient composition.
5.5.6. All the finger millet products had the shelf-life of 6 months at room temperature when packed in tri laminate pouches.

5.6: Effect of Processing on Starch Components of Finger Millet

5.6.1 In finger millet flour / starch oil interaction system, the digestibility of finger millet flour and finger millet starch decreased by 11 to 31% and 7 to 44% respectively, as the concentration of oil increased from 2 to 10%.

5.6.2 In finger millet flour / starch oil interaction, starch digestibility in flour system was not much affected with type of oil and it ranged from 7.25 to 7.82 mg/g except for mustard oil 8.79 mg/g which had slightly higher digestibility.

5.6.3 In finger millet flour / starch oil interaction, starch digestibility in finger millet starch system was found to be higher as compared to flour but the pattern with reference to oils remained same.

5.6.4 In finger millet flour / starch oil interaction, the starch digestibility was affected with the addition of protein both in flour and starch system. The starch digestibility in flour system reduced from 20-29% while in starch system it ranged from 32-38%.

5.6.5 In finger millet flour / starch oil interaction, the complexing index progressively increased with the increase in levels of oils both in flour and starch system. The complexing index in flour system ranged from 13.5 to 42.10%, while for starch system, it was 15.36 to 35.05%

5.6.6 The complexing index was also affected with the type of oil used in the experiment recording highest complexing index of 28.03% for hydrogenated fat, followed by 26% for groundnut oil, 22.08% for palm oil and 17.16% for sunflower oil.

5.6.7 In finger millet flour/starch – oil interaction, the starch fraction readily digestible starch decreased in flour system by 13.48 to
4.73 and in starch system by 28.5 to 15.9% as compared to native flour, while slowly digestible starch increased by 20.7% in flour and 32.16% in starch system.

5.6.8 At 5% concentration of different oils, the decrease in readily digestible starch was 16.65% in flour system and 36.28% in starch system and increase in slowly digestible starch was 30% in flour system and 64.5% in starch system respectively as compared to native flour and starch without oil.

5.6.9 At 5% concentration of proteins, the readily digestible starch and slowly digestible starch both decreased in flour and starch system. The decrease in readily digestible starch was 24.10% while slowly digestible starch was 6.6% and was found to be higher with whey protein as compared to casein and soya protein in flour system. The same pattern was also found with starch system.

5.6.10 At 5% concentration of whey protein and soya protein and lipids, there was decrease in readily digestible starch by 46.68% and 48.51% in flour system and 42.36% and 38.69% in starch system respectively.

5.6.11 The slowly digestible starch also decreased in both flour and starch system. The decrease in slowly digestible starch was 9.92% and 13.23% in flour system and 25.67% and 15.51% in starch system with whey and soya protein respectively.

5.6.12 The resistant starch increased as oil concentration increased. The resistant starch increased from 40.40 to 67.67% in flour system, while it was 68.96 to 80.45% with starch system.

5.6.13 Resistant starch increased with the incorporation of the oils used in the experiment and found to be higher in case of groundnut oil 64.64 and 89.65% and lowest in mustard oil 50.5 and 95.4% with flour and starch system respectively.

5.6.14 Resistant starch was increased with the addition of proteins. The increase in resistant starch formation in flour system with whey
protein was 50.5%, with casein 63.6% and with soya 33.3%, while in case of starch system it was 98.8% with whey, 77% with casein and 46% with soya protein.

5.6.15 The three way interaction was relatively higher both in flour/starch systems with sunflower oil and whey protein, and there resistant starch formation was also higher as compared to native flour.

5.6.16 In finger millet flour/starch –oil – protein interactions, the readily digestible starch decreased and slowly digestible starch and resistant starch increased with the addition of oil or protein which infers the increased functionality of flour / starch.

5.6.17 In flour / starch lipid interactions with different type of oils, Differential scanning calorimetry thermograms revealed that gelatinisation temperature was decreased to 51°C with hydrogenated fat in flour system while in starch system it was reduced to 63°C with coconut oil and sunflower oil.

5.6.18 The pasting properties as per the visco-amylograph studies revealed that cold paste viscosity increased with the concentration of oil incorporated in both flour and starch system.

5.7: Studies on Resistant Starch and their Structural Characteristics

5.7.1 In native finger millet, RS₁, RS₂ and RS₃ were 3.46, 2.33 and 30.86% respectively.

5.7.2 During puffing the RS₁ and RS₂ decreased by 21.09% and 23.17% while RS₃ increased by 35.87%.

5.7.3 The SEM photomicrographs revealed that majority of native ragi starch granules appeared to be irregular in shape, with definite outline while, in puffed flour samples, the expansion of granules at the center resulted in flattening of the particles giving an irregular shape.
5.7.4 The SEM photomicrographs of RS$_1$ fraction of native samples showed the oval shaped granules as well as breakdown of granular structure while in puffed flour, the bigger irregular shaped particles were observed.

5.7.5 In native and puffed finger millet flour samples RS$_2$ and RS$_3$ showed a complete disintegration of starch structure. In RS$_2$ small pores were seen on the surface of the granules while in RS$_3$ fissures and small pits were seen on the surface.

5.7.6 The SEM studies of resistant starch fractions indicated that structure of starch particles disintegrated and relatively more prominent in RS$_2$ and RS$_3$ fractions than in RS$_1$ fraction.

5.7.7 The X-ray diffraction of native and puffed finger millet flour showed A-type diffraction pattern as found in other cereals.

5.7.8 In native finger millet flour RS$_1$ showed A-type, RS$_2$ B-type and RS$_3$ V and B-type pattern.

5.7.9 In puffed finger millet flour RS$_1$ showed A-type, RS$_2$ C-type and RS$_3$ V and B-type pattern.

5.7.10 The X-ray diffraction of finger millet resistant starch fractions and their effect on puffing showed a varied pattern indicating the change in crystallinity.