Physico-chemical effects of irradiation on starch and protein of maize and bean flours

BY

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I declare that the thesis herewith submitted for the PhD degree at the University of Pretoria, had not been previously submitted by me for a degree at any other University.

ABSTRACT

PHYSICO-CHEMICAL EFFECTS OF IRRADIATION ON STARCH AND PROTEIN OF MAIZE AND BEAN FLOURS

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The high viscosity of starch based weaning foods made from cereals, legumes and tubers, is a major impediment to adequate intake of energy and proteins in developing countries. Infants, with stomach capacity of only 220-250 ml and undeveloped digestive systems, can only consume porridges of viscosity of 1000-3000 cP. To achieve this consistency, traditional weaning foods are normally diluted to about 5-10% total solids content. However, weaning foods need to contain at least 20% total solids content to meet their nutritional requirements. Cereal based weaning foods are also poor in protein quality but this can be improved by combining cereals (e.g. maize) with legumes (e.g. beans) at 70/30 ratio.

To meet the consistency and total solids requirements for infant porridges, maize flour, bean flour and their 70/30 composite flours were irradiated at 0, 2.5, 5.0, 7.5 and 10 kGy. Irradiation significantly reduced the viscosity of porridges made from these irradiated flours. Porridges of 20% total solids content and the desired consistency consumable at 30-50 °C could be prepared from bean flours irradiated at 5.0 kGy while maize and the 70/30 composite flours needed at least 7.5 kGy. The reduction in viscosity of these porridges was probably due to debranching and depolymerisation of amylopectin starch fractions.

Irradiation had significant ($p \leq 0.05$) effects on starch digestibility of maize and bean flours and porridges made thereof. Irradiation of maize flour increased the *in vitro* starch digestibility of porridges at 2.5 kGy by 3.2% but at 10 kGy it decreased by 2.8% compared to the control. In porridges made from irradiated bean flours, there was an increase of 8.8% in the *in vitro* starch digestibility at 2.5 kGy and a decrease of 2.1% at 10 kGy compared to the control. The observed increase in starch digestibility *in vitro* at 2.5 kGy was probably due to increased access of enzymes to starch molecules due to debranching and depolymerisation of amylopectin molecules, reduced viscosity of the porridges and increased solubility of the starch molecules.

Experiments were performed to determine the probable chemical reactions that might have caused decreases in starch digestibility at doses higher than 2.5 kGy. It was established that irradiation caused browning, which may be due to Maillard reactions. Maillard reactions produce chemical species that may inhibit α-amylase enzymes. Using differential scanning calorimetry (DSC) it was established that irradiation at higher doses caused increased crystallinity of amylopectin molecules which could have led to lower degree of gelatinisation and subsequently reduced starch digestibility. Using lichenase and α-amylase enzymes, it was established that irradiation at higher doses led to formation of less digestible β(1-3) and β(1-4)-bonded starch. HPLCSEC experiments showed that higher doses led to more debranching of amylopectin molecules, probably resulting in the production of more retrogradable short chain amylose molecules in maize and bean starches.

Irradiation of maize and bean flours at 0-10 kGy had very little effects on their protein digestibility compared to starch digestibility, probably due to the large size of amylopectin fractions of starches in maize and bean flours.

Irradiation processing shows a high potential for use to increase the total solids content of porridges. However, the small changes in starch digestibility of porridges made from irradiated maize and bean flours should be investigated further.

UITTREKSEL

FISIES-CHEMIESE EIENSKAPPE VAN BESTRALING OP STYSEL EN PROTEÏENE VAN MIELIE- EN BOONTJIEMELE

deur

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Die hoë viskositeit van styselgebaseerde speenpappe, wat van grane, peulgewasse en knolle gemaak word, is geïdentifiseer as 'n belangrike struikelblok vir die opname van energie en proteïene vir suigelinge en jong kinders in die meeste ontwikkelende lande. Suigelinge en jong kinders het 'n baie klein maagkapasiteit van 200-250 ml en as gevolg van hulle onderontwikkelde spysverteringstelsel kan hulle slegs voedsel met 'n viskositeit van 1000-3000 cP inneem. Om hierdie viskositeit te verkry word die tradisionele speenvoedsels normaalweg verdun tot omtrent 5-10 % totale vastestofinhoud. Speenvoedsel moet egter minstens 20% totale vastestofinhoud hê om aan die energie- en proteïenbehoeftes van suigelinge en jong kinders te voldoen. Graangebaseerde speenvoedsels het verder ook 'n lae proteïenkwaliteit maar dit kan verbeter word deur grane (bv. mielies) met peulgewasse (bv. boontjies) te kombineer in 'n 70/30 verhouding.

Mieliemeel, boontjiemeel en die 70/30 mielie:boontjie gemengde mele is bestraal teen 0, 2.5, 5, 7.5 en 10 kGy ten einde aan die konsistensie-en totale vastestofinhoudvereistes van speenvoedsels te voldoen. Hierdie studie bevestig dat bestraling betekenisvolle verlagings in die viskositeit van hierdie mele teweeg bring en dat die vastestofinhoud van die pappe verhoog kon word tot 20%, die vlakke waar dit voldoen aan suigelinge en jong kinders se energie- en proteïenbehoeftes. Deur bestraling van die mieliemeel en 70/30 mengsel van

mielie- en boontjiemeel teen 7.5 kGy kon die totale vastestofinhoud verhoog word tot 20% en steeds inneembaar wees tussen 30 en 50 °C. Boontjiemele moes teen 5 kGy bestraal word om aan bg. vastestofinhoudstandaarde te voldoen by 30 tot 50 °C. Die verlagings in viskositeit van pappe gemaak van mieliemeel, boontjiemeel en hulle 70/30 gemengde meel is waarskynlik toeskryfbaar aan depolimerisasie en onttakking van die amilosepektienstyselfraksies.

Bestraling het betekenisvolle ($p \leq 0.05$) effekte gehad op styselverteerbaarheid van mielie-en boontjiemele asook hul pappe. In pappe gemaak van mieliemeel het bestraling 'n verhoging van 3.2% by 2.5 kGy in *in vitro* styselverteerbaarheid veroorsaak en 'n afname van 2.8% by 10 kGy, in vergelyking met die kontrole. In pappe gemaak van boontjiemeel het bestraling 'n verhoging van 8.8% in *in vitro* styselverteerbaarheid tot gevolg gehad by 2.5 kGy en 'n verlaging van 2.1% by 10 kGy, gemeet aan die kontrole. Die verhoging in *in vitro* styselverteerbaarheid teen 2.5 kGy bestraling was waarskynlik toe te skryf aan die verhoogde beskikbaarheid van styselmolekules aan ensieme, veroorsaak deur die aftakking en depolimerisasie van amilopektienmolekules, verlaagde viskositeit van pappe en verhoogde oplosbaarheid van styselmolekules.

Eksperimente is uitgevoer om te bepaal wat die moontlike chemiese reaksies is wat verantwoordelik was vir die verlaagde styselverteerbaarheid by dosisse hoër as 2.5 kGy. Hierdie studie het bevestig dat bestraling verbruining veroorsaak, wat wel moontlik aan Maillardreaksies te wyte mag wees. Maillardreaksies produseer chemiese spesies wat amilase ensieme inhibeer. Dit is verder bevestig deur differensiële skanderings kalorimetrie (DSC) dat bestraling veranderings in die kristalliniteit van amilopektien veroorsaak in beide boontjie- en mieliemele, waarskynlik a.g.v. die onttakking van die amilopektienmolekules. Verhoogde amilopektienkristalliniteit kon gelei het tot 'n mindere mate van gelatinisasie, en gevolglik verlaagde styselverteerbaarheid. Deur gebruik te maak van ligenase en α-amilase ensieme, is vasgestel dat bestraling by hoër dosisse lei tot die ontstaan van minder verteerbare $\beta(1\text{-}3)$ en $\beta(1\text{-}4)$ gebonde stysel.

Dit is ook bevestig, deur gebruik te maak van grootte-uitsluitings-hoë-verrigtings-vloeistofchromatografie (HPLCSEC), dat bestraling van mielie- en boontjiemeel tot aftakking van amilopektien molekules lei. Afgetakte amilopektienmolekules het die vorming van geretrogradeerde kort-ketting amilose molekules tot gevolg.

Bestraling van mielie- en boontjiemele teen 0-10 kGy het baie min uitwerking gehad op die proteïenverteerbaarheid moontlik a.g.v. die groter grootte van die amilopektienfraksies van stysels in mielie-en boontjiemele.

Bestralingsprosessering beskik oor die hoë potensiaal om die totale vastestofinhoud van pappe te verhoog. Die klein verskille in styselverteerbaarheid in pappe gemaak van bestraalde mielie- en boontjiemele moet egter verder ondersoek word

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