CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Gamma irradiation significantly ($p \leq 0.05$) reduces the viscosity of porridges made from maize flour, bean flour and their 70/30 maize:bean composite flour. The viscosity reductions in the porridges are dose dependent with greater decreases at higher doses. This is probably due to depolymerisation and debranching of amylopectin molecules.

Maize flour requires an irradiation dose of at least 7.5 kGy to prepare porridge of total solids content of 20%, with a consistency of between 1000-3000 cP at a setback temperature of 40-50°C. For the porridge of the same total solids content, bean flour needs at least a minimum dose of 5 kGy to give a consistency of 1000-3000 cP at 30-50°C. For the porridge to have a viscosity of 1000-3000 cP and total solids content of 20% at 40-50°C the 70/30 maize:bean composite flour needs to be irradiated at 7.5 kGy. Porridge made from irradiated maize flour exhibits a higher viscosity than porridge made from irradiated bean flour at the same dose level. When flour is heated in water, the resistance to flow (viscosity) is caused by swelling of amylopectin molecules and maize flour with higher amylopectin content swells more than the bean flours.

When viewed by the scanning electron microscopy, there are no visible changes in the size and shape of both maize and bean flour starch granules due to irradiation up to 10 kGy. Bean starch granules are about two to three times as large as the maize starch granules and this may explain the differences observed in effects of irradiation on some of the molecular properties of maize and bean starch isolated from the treated flours.

While the effects of irradiation on porridge viscosity are rather clear its effects on starch digestibility are not. Irradiated maize and bean flours had a maximum *in vitro* starch digestibility at 2.5 kGy. At doses above 2.5 kGy, there were significant decreases in *in vitro* starch digestibility in both raw flours and porridges made from maize and bean flours compared with the control. However, in raw flours and porridges made from

irradiated bean flours, the *in vitro* starch digestibility was higher than the control at 2.5, 5.0 and 7.5 kGy and lower than the control only at 10 kGy. Irradiation at 2.5 kGy caused an increase of 3.2% in starch digestibility of porridge made from maize flour compared to the control and a decrease of 2.8% at 10 kGy compared to the control. In porridge made from bean flour, irradiation caused an increase in starch digestibility of 8.8% at 2.5 kGy and a decrease of 2.1% at 10 kGy compared to the control.

Porridges made from irradiated bean flour have higher increases in starch digestibility than porridges made from irradiated maize flour at 2.5 kGy and this is due to differences in starch granule sizes. Overall, porridges made from irradiated maize flour have higher starch digestibility than the porridges made from irradiated bean flour and this is probably due to differences in amylose fraction content of starch of maize and bean flours.

At 2.5 kGy, irradiation results in increased starch digestibility in raw and cooked maize and bean flours due to the opening up of starch molecules by depolymerisation in general and debranching of amylopectin molecules in particular (Figure 26). Irradiation at the same dose has more effect on larger particles and bean starch granules are about 2-3 times larger than maize starch granules.

Models showing the possible effects of irradiation on properties of starch that may explain the changes observed in starch digestibility are summarised in Figures 25, 26 and 27.

Irradiation causes Maillard reactions in both maize and bean flours as indicated by colour changes and this may lead to reductions in starch digestibility due to the production of α-amylase inhibitors (Figure 25).

Irradiation results in the development of β-bonded starch possibly through transglucosidation and this increases with the dose of irradiation (Figure 27). It was observed that the reducing sugar contents of porridges made from irradiated flour

hydrolysed using endo (1-3) (1-4) β-D-glucanase (lichenase) enzyme in combination with α-amylase were higher compared to the reducing sugar content released by irradiated starch treated with α-amylase alone. More β-bonded starch is produced in bean flour (0.75%) than in maize flour (0.45%) at 10 kGy, probably due to the large size of bean starch granules compared to maize starch granules. Beta-bonded starch is only partially digestible by α-amylases and behaves like resistant starch.

Irradiation causes debranching of amylopectin fractions of starch molecules. Debranched amylopectin molecules exhibit increased crystallinity of starch in maize and bean flours. Increased crystallinity results in decreased degree of gelatinisation in porridges made from these flours which results in reduced starch digestibility (Figure 27). HPLCSEC data indicates that irradiation caused debranching of amylopectin (Figure 27). Debranched amylopectin also results in the production of short chain amylose molecules, which are resistant to hydrolysis by α-amylases *in vitro*.

The most likely causes of decreased starch digestibility of maize and bean flours *in vitro* are increased crystallinity of amylopectin caused by debranching. Increased crystallinity results in higher enthalpy of gelatinisation and higher temperature of gelatinisation, both of which results in reduced degree of gelatinisation and this may cause reductions in starch digestibility *in vitro*. Depolymerisation and/or debranching of amylopectin produces highly retrogradable short chain amylose molecules and this may also lead to decreased starch digestibility. Formation of β-bonded starch in flours of maize and beans during irradiation is another cause of decreased starch digestibility.

Irradiation at 0-10 kGy has very little effect on protein digestibility probably due to the protection by the large molecular weight amylopectin fractions in the starch. Larger amylopectyin fractions of starch are affected more by irradiation than the smaller molecular weight components of maize and bean flours.

Irradiation processing offers a high potential for use in increasing total solids content of porridges made from starchy cereals and legumes due to its effects of debranching and

depolymerisation of starch in general and debranching of amylopectin in particular. There are some small but significant reductions in starch digestibility of porridges at 10 kGy (2.8% for maize and 2.1% for bean flours) but these can be outweighed by the ability to prepare porridges of higher total solids content with acceptable consistency.

Further research using other more advanced techniques such as X-ray diffraction, nuclear magnetic resonance, near infra-red spectroscopy and Raman spectroscopy may be used in future to elucidate the exact reactions that take place in cereal and legume flours during irradiation. Differential scanning calorimetry is reported as able to bring out very small changes in the molecular properties of proteins in irradiated foods. More work should be done using DSC to determine molecular changes in proteins during irradiation of different foods. The safety of irradiated foods for use as weaning foods may have to be studied further using weanling rats to clarify the effects of resistant starch formed during irradiation.

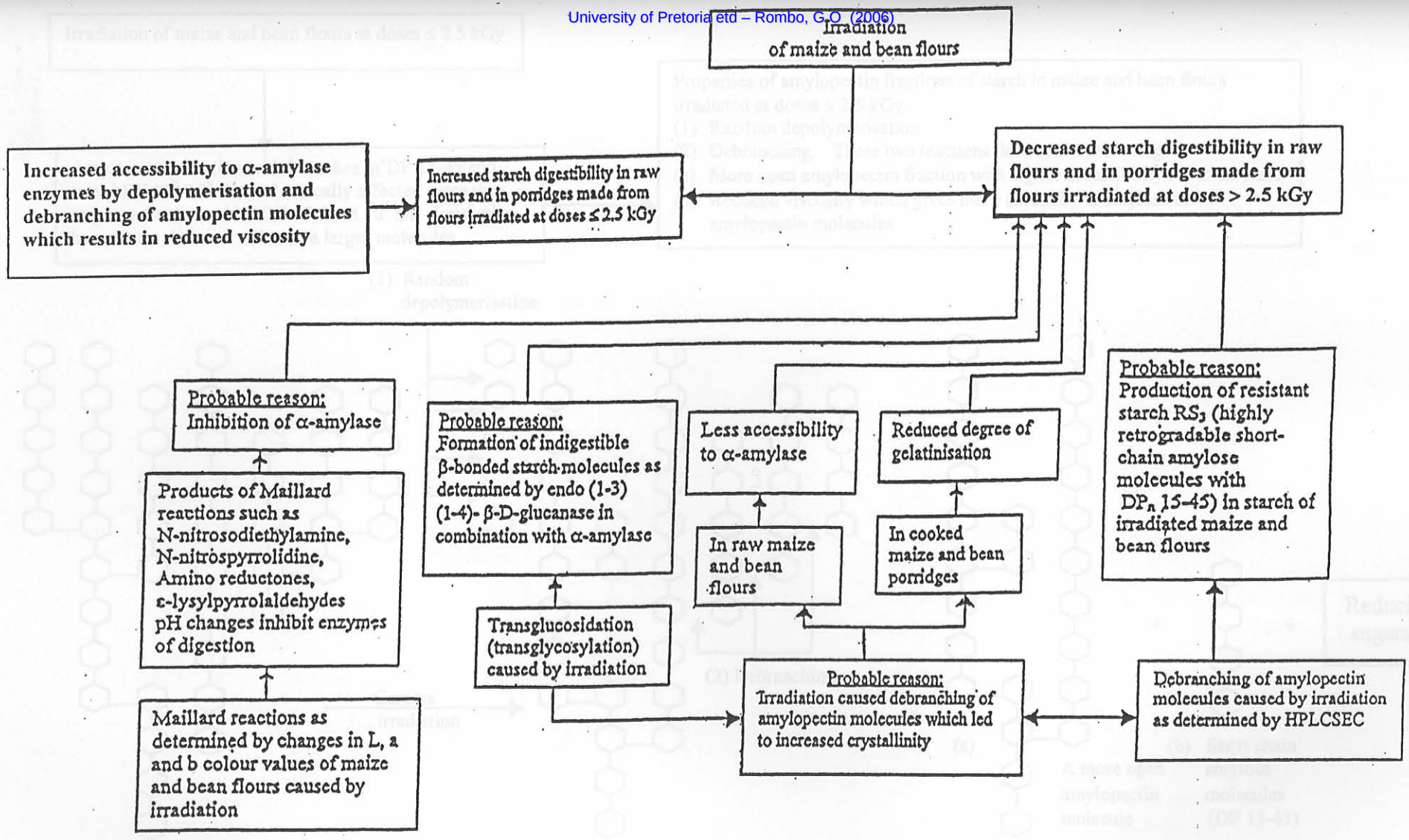

Figure 25 Proposed reasons for changes in *in vitro* starch digestibility of raw and cooked irradiated maize and bean flours

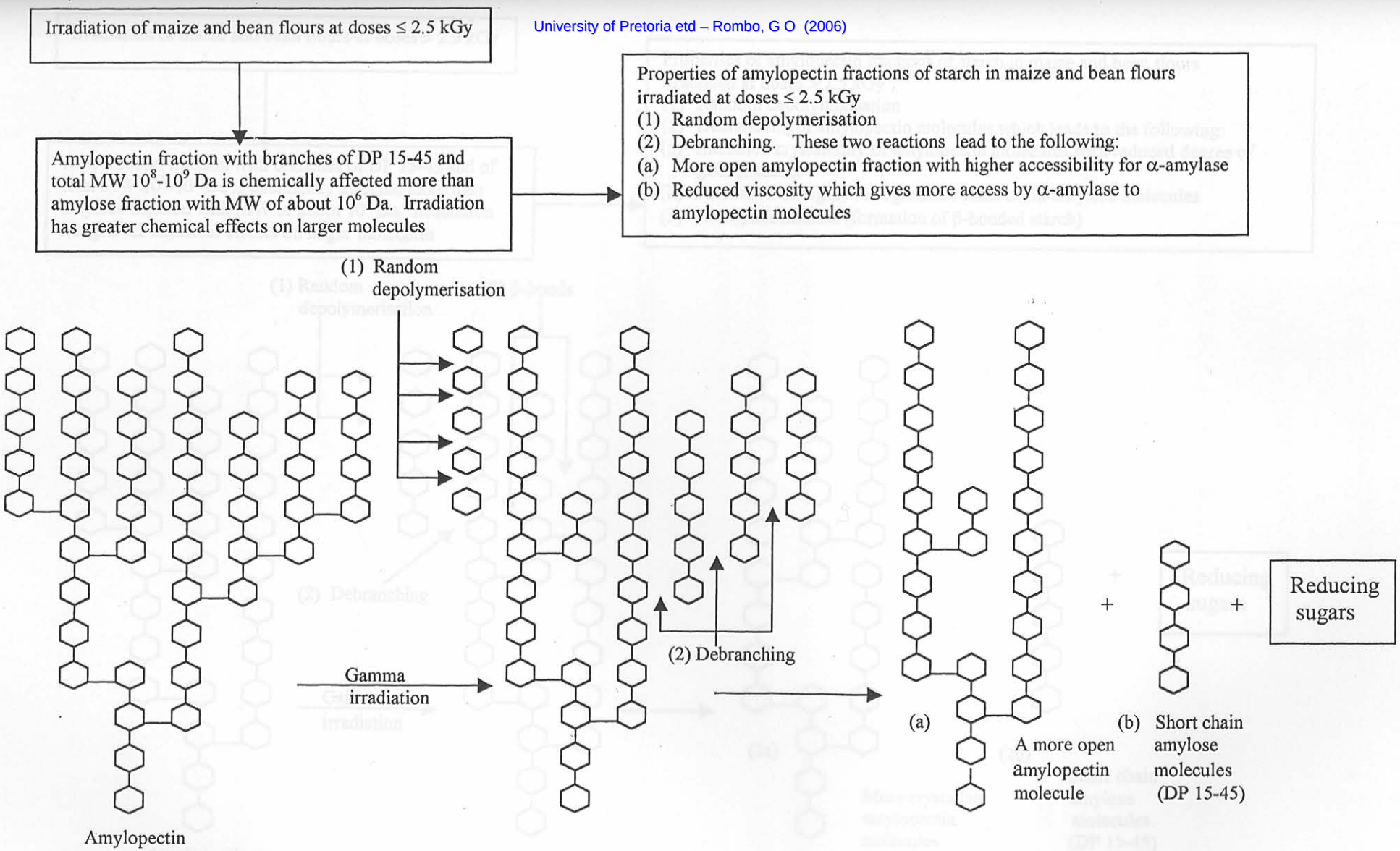

Figure 26 Probable effects of irradiation on amylopectin molecules of maize and bean flours at doses ≤ 2.5 kGy

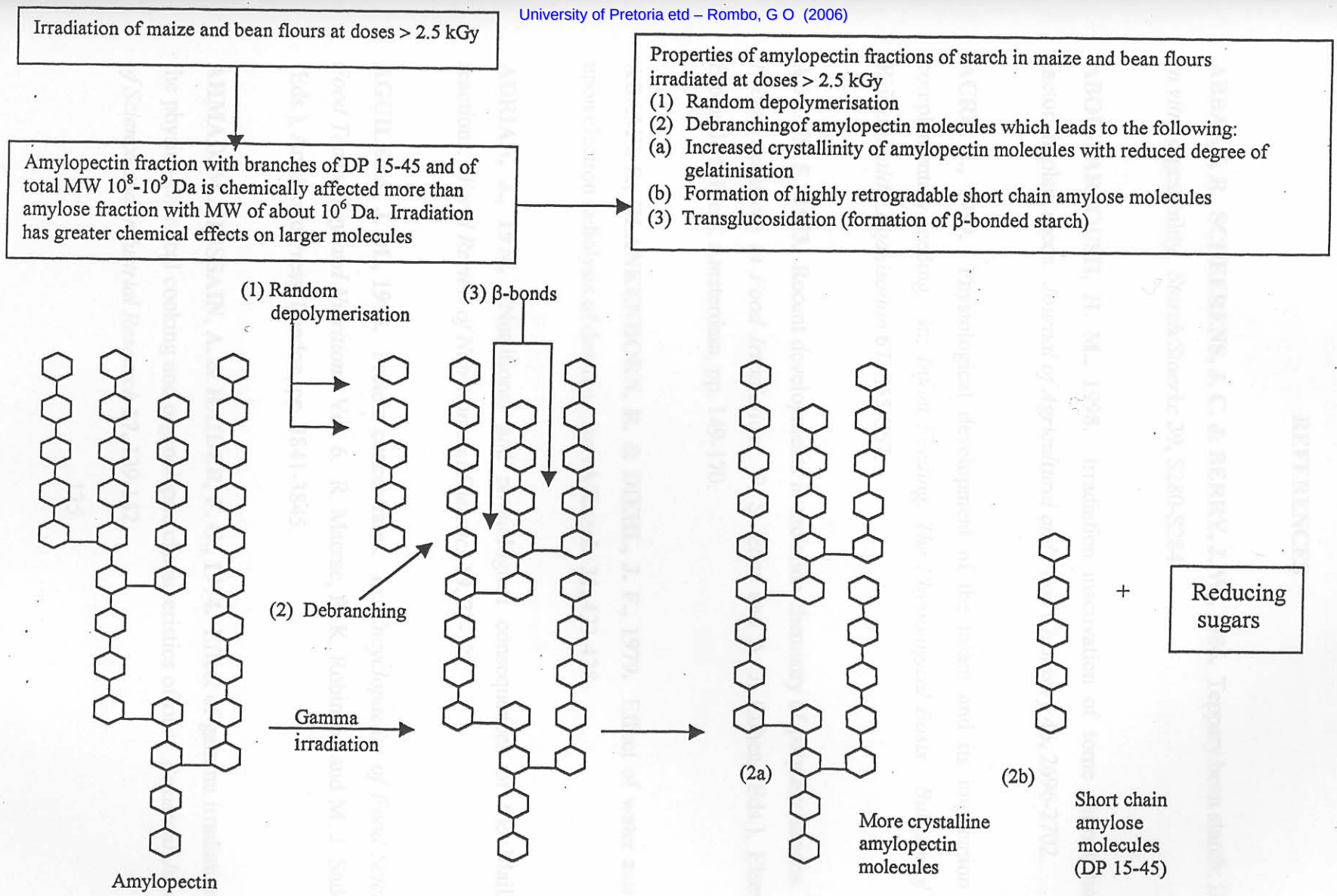

Figure 27 Probable effects of irradiation on amylopectin molecules of maize and bean flours at doses > 2.5 kGy