



On-farm evaluation of the impact of drying and storage on the carotenoid content of orange-fleshed sweet potato (*Ipomea batata* Lam.)

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Review

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3 1 **On-farm evaluation of the impact of drying and storage on the**
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6 2 **carotenoid content of orange-fleshed sweet potato (*Ipomea batata***
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9 3 **Lam.)**

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11 4 **Running head: On-farm carotenoid loss in sweet potato chips**
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16 6 Aurélie Bechoff^{1*}, Keith Tomlins¹, Claudie Dhuique-Mayer², Richard Dove³ and
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18 7 Andrew Westby¹

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21 8 ¹*Natural Resources Institute, University of Greenwich, Central Avenue, Chatham Maritime,*
22
23 9 *Kent ME4 4TB, United Kingdom.*

24
25
26 10 ²*Centre International de Recherche Agronomique pour le Développement (CIRAD) UMR*
27
28 11 *Qualisud, TA 95B/16, 34398 Montpellier, France*

29
30 12 ³*HarvestPlus Reaching End Users Project, World Vision, CP 517, Rua de Resistencia,*
31
32 13 *Quelimane, Mozambique*

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34
35 14 *Correspondence to: Aurelie Bechoff, Natural Resources Institute (NRI), University of
36
37 15 Greenwich, Central Avenue, Chatham, Kent ME4 4TB, UK. Email: a.bechoff@gre.ac.uk
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42 17 **Abstract:** Drying of orange-fleshed sweet potato was evaluated under African rural
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44 18 conditions. Three locally-built dryers (open air-sun; tunnel and shade) were tested using
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46 19 Resisto and MGCL01 varieties in Mozambique. Total carotenoid losses were low in all dryers
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48 20 being 9.2% on average. After drying sweet potato chips were stored in a traditional way (jute
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50 21 bags inside a mud house). Chip size (thin, thick chip or slice) had a significant effect on
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52 22 drying ($p < 0.05$) but not on storage; and variety had an effect on both. Total carotenoid losses
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54 23 during storage were much higher being 83.7% on average, after four months, with main
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56 24 individual carotenoids fitting a first order kinetics degradation. Globally carotenoid losses on-
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58 25 farm or on-research station, were of similar level.

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3 26 **Keywords:** *Ipomea batata* (L.) Lam, carotenoids, storage, drying, on-farm, on-research.
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8 28 **INTRODUCTION**
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10 29 Mozambique is one of the poorest countries in the world, and additionally, one of the most
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12 30 affected by vitamin A deficiency; 71% of the children under five are deficient (Aguayo &
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14 31 Baker, 2005). White-fleshed sweet potato (WFSP) is traditionally part of the Mozambican
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16 32 diet, as a source of carbohydrate. An integrated agricultural and nutritional intervention
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18 33 involving households with young children in rural areas of Mozambique has demonstrated
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20 34 that regular consumption of orange-fleshed sweet potato (OFSP), rich in β -carotene,
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22 35 significantly improved the vitamin A status of the children (Low *et al.*, 2007). The marketing
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24 36 and consumption of OFSP in Mozambique has increased as a result of initiatives by Centro
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26 37 Internacional de la Papa (CIP) and Instituto de Investigação Agrária de Moçambique (IAAM),
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28 38 and recent promotion programmes, such as the HarvestPlus Reaching End Users Project
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30 39 (2006-2010). New ways of consuming OFSP in forms such as juice, bread and confectionary
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32 40 products are being investigated in order to extend the availability and nutritional benefits
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34 41 through both home consumption and trade. The availability of fresh sweet potato is seasonal
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36 42 and storage of the fresh root beyond 3 months is difficult (Tomlins *et al.*, 2007). Hence the
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38 43 production of dried products could potentially extend the availability of sweet potato by up to
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40 44 4-6 months. Sun-drying of sweet potato is a traditional processing practice in many
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42 45 developing countries including a number of African countries (Woolfe, 1992). Although sun-
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44 46 drying of sweet potato has been reported in Mozambique (Dove R., pers. comm.), reports
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46 47 have been scarce. A World Vision survey for OVATA in Zambezia district, Mozambique
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48 48 (van Straaten, 2006) indicated that about 35% of households who grow sweet potato also
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50 49 practiced drying of sweet potato. Sun-drying is a non-controlled technology and previous
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52 50 studies on a range of commodities have demonstrated that the level of drying technology used
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3 51 has an impact on provitamin A carotenoid retention (Bechoff *et al.*, 2009; Chen *et al.*, 2007;
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5 52 Desorby *et al.*, 1997; Mulokozi & Svanberg, 2003; Negi & Roy, 2000). Sun-drying could
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8 53 result in higher carotenoid losses than with other technologies, such as solar-drying
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10 54 (Mulokozi & Svanberg, 2003; Negi & Roy, 2000). However recent publications (Bengtsson *et*
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12 55 *al.*, 2008; Bechoff *et al.*, 2009; Bechoff *et al.*, 2010a) have showed that carotenoid losses
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14 56 from sweet potato chips during sun-drying were low and were similar to solar-drying. In
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16 57 addition, it was demonstrated in an on-station study in Uganda (Bechoff *et al.*, 2010a), that
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18 58 losses of carotenoids were much more critical during storage for four months (70.4%) than
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20 59 during drying (9.0%). Tomlins *et al.* (2007) argued that experimental results obtained on a
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22 60 research station do not necessarily transfer to the farm situation because of variations in
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24 61 farmer knowledge and the local environment. It was therefore important to verify the on-
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26 62 station results in typical rural setting.
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34 64 In order to better preserve provitamin A in sweet potato drying, there was a further need to
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36 65 determine whether process variables influence carotenoid degradation and the rate of
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38 66 degradation during storage. In an on-farm study, variables that can be straightforwardly
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40 67 explored are sweet potato chip size and variety. In laboratory trials, chip size has been
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42 68 reported to influence carotenoid degradation in sweet potato during sun-drying (Bechoff *et*
43
44 69 *al.*, 2009) and the variety of sweet potato has also been reported to influence carotenoid
45
46 70 degradation (Bechoff *et al.*, 2010a). Determination of kinetics of carotenoid degradation in
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48 71 dried sweet potato during storage under laboratory conditions has been reported in literature
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50 72 (Haralampu & Karel, 1983; Stephanovitch & Karel, 1982) but field studies measuring
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52 73 carotenoid kinetics in dried food commodities such as sweet potato are scarce. The
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54 74 determination of carotenoid degradation rate under on-farm conditions could bring a practical
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3 75 help to farmers and millers with the evaluation of dried OFSP shelf life that could potentially
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5 76 lead to an improvement of the product quality.
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8 77 The aim of the study was to evaluate simple and low-cost drying and storage for orange-
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10 78 fleshed sweet potato (OFSP) on-farm. The main objective was to measure the level of
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12 79 carotenoid loss after solar and sun drying and over a four-month storage period taking into
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14 80 account the effect of variety and chipping.
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18 82 **MATERIALS AND METHODS**

19 83 **Root samples**

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23 84 Mature sweet potato roots (MGCL01 and Resisto varieties), about 80 kg per variety, were
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25 85 purchased from farmers around Lualua, Zambézia Province, Mozambique (105 km from
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27 86 Quelimane, the Province Capital). The exact root harvest age was not known. All roots were
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29 87 processed within one to three days after harvest.
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35 88 **Dryers**

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38 89 Three dryers were constructed on a farm belonging to a subsistence farmer at Lualua. Apart
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40 90 from the greenhouse clear plastic (Strawberry 3 seasons BPI-VISQUEEN®, UK thickness
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42 91 150 µm), all building materials were obtained locally and constructed by local craftsmen.
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44 92 Each of the dryers was mounted on a simple wooden structure that was fitted with straw mats.
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46 93 - The tunnel dryer had similar dimensions to the on-research station dryer in Uganda (Bechhoff
47
48 94 *et al.*, 2010a). It had a total length of 9 m and a width of 1.5 m. The collector (absorber)
49
50 95 occupied the first 3.5 m and was formed of an iron metal sheet. The rest of the dryer (5.5 m)
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52 96 was used as drying area. The floor of the drying area was made of straw mats covered with
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54 97 black plastic sheeting to insulate the structure. Clear greenhouse plastic covered the whole
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3 98 structure apart from the inlet and outlet allowing air flow and protected by mosquito net
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5 99 (0.55m^2 each). The dryer had a 6° slope.

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8 100 - The open air dryer (exposed to direct sun) had a length of 6 m and a width of 1.5m with a
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10 101 height of 0.9m and had a 6° slope.

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12 102 - The shade dryer was identical to the open air dryer and with the addition of a grass lined
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14 103 roof. The roof was about 0.6 m larger and longer than the table in order to protect it from sun
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16 104 light. The shade dryer was flat (*i.e.* without a 6° slope) because of building constraints.

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18 105 - Each dryer could fit 6 trays of 4 kg fresh sample each and surface area per tray was 1.03m^2 .

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20 106 The geographical position of the dryers was determined using GPS (GPS 60, GARMIN®).

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22 107 Dryers were positioned facing north; this allowed maximum sun exposure in the southern
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24 108 hemisphere. Temperature/humidity dataloggers (Tinytalk 2 Geminidatalogger, Chichester,
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26 109 UK) were placed in the tunnel dryer and under the shade for ambient temperature
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28 110 measurement.

33 34 35 111 Drying

36
37 112 Drying trials were carried out in duplicate on different days (one day and three days after
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39 113 harvest). Roots were washed and spread on a black plastic under the shade for draining. Five

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41 114 fresh roots per variety were collected for carotenoid analysis. On the drying day, unpeeled

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43 115 roots were chipped using either a mechanical rotary disc chipper producing either thick and

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45 116 thin chips, or were hand-sliced (traditional way). Size (thickness, width, length) of ten fresh

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47 117 chips or slices was recorded using a digital calliper. Samples (4 kg) were weighed (Hanson

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49 118 Electronic Chrome Effect Scale; ± 1 g) after careful mixing (using a quartering technique). All

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51 119 preparation operations were carried out in the shade to minimize losses in carotenoids. Sweet

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53 120 potato samples were evenly spread on mosquito mesh trays (6 trays per dryer) at a density of

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55 121 $3.9\text{ kg}\cdot\text{m}^{-2}$. Loading time was recorded for each dryer. Samples were weighed and turned

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57 122 frequently during drying. Samples were left overnight in the dryers because rain was unlikely

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3 123 at the time of the study. Under these field conditions, the end of drying was evaluated
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5 124 subjectively by the presence of flour and a characteristic cracking noise when crushed in the
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8 125 hand. The fresh samples of chips/slices per treatment with an initial weight of 4 kg (per
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10 126 sample) reached a final weight of 1.5 kg for MGCL01 and 1.0 kg for Resisto after drying.
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13 127 Collection of dried sweet potato chips for analysis and storage

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16 128 A carefully mixed portion of dried chips/slices (about 200 g) was collected in zip-polythene
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18 129 bags and placed in a cooler bag before they were transported (within a couple of hours) to a
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21 130 freezer (-20 °C) in Quelimane. The remainder of the chips/slices were used for the storage
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23 131 study (at ambient temperature). Samples were stored in traditional bags made of jute and hung
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25
26 132 inside a house constructed from mud in Lualua. In order to measure losses during storage,
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28 133 sub-samples (200 g chips or slices per stored sample) were removed respectively after 1
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30 134 month (31 days), 2 months (62 days) and 4 months (125 days) and placed in polythene bags in
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33 135 a cooler bag and quickly transferred and stored in the freezer. The datalogger recording the
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35 136 ambient temperature during storage was unfortunately lost, but it is estimated from records
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37 137 taken nearby in Quelimane that the temperature in the mud house was on average 25 °C with
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40 138 minimum/maximum temperatures of 20/31 °C (Weather Underground Quelimane, 2007).
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43 139 Carotenoid analysis

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46 140 Chip samples in zip bags were stored at -20°C for 1-6 months before analysis because of
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48 141 delays and the low sample throughput for this method. No significant carotenoid loss was
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51 142 observed on chips in freezer in this interval ($p < 0.05$) (Bechoff 2010). Samples were milled
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53 143 into flour (particle sizes of less than 1 mm) using a Laboratory mill 3600 (Perten Instruments,
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55 144 Segeltorp, Sweden) and extracted in duplicate in a randomised order. Carotenoids were
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58 145 identified and quantified using the method described by Bechoff *et al.* (2010b). The extraction
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60 146 stage was adapted from Rodriguez-Amaya and Kimura (2004). A portion of the homogeneous

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3 147 representative sample (0.4-2.0 g of flour) was re-hydrated for 20 min in 10 ml deionised
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5 148 water, homogenised with 50mL methanol:tetrahydrofuran (THF) (1:1) for 1 minute and
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8 149 filtered. The homogenised extract was rinsed with methanol:THF (1:1) until there was no
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10 150 yellow colour left in the filtrate. Partition between the aqueous phase and organic phase
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12 151 containing the carotenoids was achieved by addition of petroleum ether (PE -40-60° C). The
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15 152 PE phase was further washed with water, dried by addition of anhydrous sodium sulphate,
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17 153 then filtered and made up to volume (50 ml). For the determination of total carotenoid
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19 154 content, absorbance was measured at 450 nm using a diode array Hewlett Packard 8452A
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21 155 spectrophotometer. For the determination of individual carotenoids by HPLC, the carotenoid
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23 156 extracts in PE were dried by flushing with nitrogen in a dry block system at 35° C. The
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25 157 extracts were dissolved in 1 ml dichloromethane:MTBE (methyl tert-butyl ether): methanol
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27 158 50:40:10. Reverse-phase high performance liquid chromatography using an Agilent 1100
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29 159 system (Massy, France) was used following the method of Dhuique-Mayer *et al.* (2007).
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31 160 Carotenoids were separated through a C₃₀ reverse phase column (250 x 4.6 mm i.d.) packed
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33 161 with 5µm YMC (EUROP GmbH, Germany) at a flow rate of 1 ml.min⁻¹, a column
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35 162 temperature at 25° C and an injection volume of 20 µl. Concentrations were determined by
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37 163 comparison to a standard curve using pure β- carotene (Extrasynthese, Genay, France).
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165 Dry matter determination

50 166 Samples were collected for dry matter determination, before and after drying at the same time
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52 167 as for carotenoids analysis. Determinations were made by drying triplicate 5 g samples at 105
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54 168 °C to constant weight (minimum 24h) (AOAC, 1984).
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3 169 Statistical analyses and calculation of carotenoid degradation rates
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6 170 Normality of sample distribution was tested using Shapiro-Wilk and Kolmogorov Smirnov
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8 171 tests ($p < 0.05$). Analysis of variance (ANOVA) was carried out to determine whether there
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10 172 were significant differences between samples with one up to four factors. A significant
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12 173 difference between samples was determined by a Tukey test. Data were processed on SPSS
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14 174 15.00 (SPSS UK Ltd. Woking, Surrey, UK) for Windows software.
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20 176 Linear regression (on Excel) was used to determine the rate of degradation k following the
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22 177 formula $C = C_0 - kt$ (zero order kinetics) or $\ln C = \ln C_0 - kt$ (first order kinetics) where C_0
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24 178 is the total carotenoid content after drying ($\mu\text{g}\cdot\text{g}^{-1}$); C the total carotenoid content at storage
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26 179 time t ($\mu\text{g}\cdot\text{g}^{-1}$); k the rate constant (days^{-1}) and t the storage time (days).
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31 32 181 **RESULTS AND DISCUSSION**

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37 183 Effect of dryer on total carotenoid loss

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39 184 Independently of the dryer or variety, average total carotenoid loss during drying was 9.2%.
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41 185 In all cases, levels of loss were less than 24.6% (Table 1). Effect of different factors (new
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43 186 chipper and traditional slicing) and three dryers (shade; sun; tunnel) on the two varieties was
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45 187 evaluated on total carotenoid losses (Table 2). The type of dryer had a significant effect
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47 188 ($p < 0.01$) on total carotenoid loss. Because control over drying was limited in these field
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49 189 conditions, dry matter was included as covariate in the analysis of variance from data
50
51 190 presented in Table 2. The three dryers gave significantly different results of loss: on average
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53 191 there were 13.0%, 10.0% and 1.9% for the tunnel dryer; open air dryer and shade dryer
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55 192 respectively (Table 1). Slight but significantly lower retention of total carotenoids in the
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57 193 tunnel dryer compared to the open air dryer could be explained by the higher temperature
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3 194 during drying (up to 55°C whilst the ambient temperature did not go above 33°C) (Table 1).
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5 195 There was furthermore an issue with moisture evacuation from the product in the tunnel
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8 196 dryer, which is illustrated by the maximum 100% relative humidity reached at night. This
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10 197 may have resulted from a disadvantageous wind direction at this time of the year, blowing
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12 198 East-West, whereas the tunnel was positioned North-South. As compared with the on-station
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15 199 study (Bechoff *et al.*, 2010a) using a similar but optimally oriented tunnel dryer, the on-farm
16
17 200 tunnel dryer showed some technical limitations in terms of air flow circulation. In terms of
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19 201 carotenoid losses, the difference in the tunnel and open-air sun dryers (using chips of the same
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21 202 size) was not significant (9.0% for the tunnel and open-air sun dryers in the earlier on-station
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23 203 study) (Bechoff *et al.*, 2010a) and small (13% and 10% respectively working with thin chips
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25 204 in this on-farm study). The tunnel dryer however protected against insects and rain. This type
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27 205 of dryer was mostly designed for experimental use and, because its cost was estimated to be
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29 206 ten times the cost of an open air dryer and five times that of a shade dryer, mainly due to
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31 207 imported materials, it would not be a feasible proposition for Mozambican farmers to adopt.
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34 208 The open air and shade dryer would be the dryers most suited to rural situation in
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36 209 Mozambique because of their improved carotenoid retention, lower cost and availability of
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38 210 most materials locally (on the farm or in the next village).
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46 212 Complete protection from sun light and lower temperatures for shade-drying compared to
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48 213 tunnel and open air sun dryers can explain the improved carotenoid retention from shade
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50 214 drying. In this study, from an overall product quality perspective, the shade dryer worked well
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52 215 with thin chips but was not well adapted to handcut slices (traditional way) because of longer
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54 216 drying times leading to off-odours. Researchers, working with different commodities, have
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56 217 reported conflicting results regarding carotenoid losses during shade-drying. Chavez *et al.*
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58 218 (2007) reported that shaded-dried yellow cassava that contained carotenoids had improved
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3 219 carotenoid retention compared to sun-dried one, while Negi & Roy (2000), working on leafy
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5 220 vegetables, reported that higher carotenoid losses were obtained in shade and sun-drying as
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8 221 opposed to solar (cabinet) drying. These inconsistencies in the literature could be the result
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10 222 from different environmental conditions (temperature, humidity and wind) and different
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12 223 product characteristics influencing carotenoid retention during drying.
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17 225 Effect of chipping on total carotenoid loss after drying

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19 226 Traditional slices, thick and thin chips had an average thickness of about 5.2 mm, 2.9 mm and
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21
22 227 0.4 mm respectively. The effect of chipping treatment using three chipping treatment is
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24 228 reported in open air drying for both MGCL01 and Resisto varieties (Table 1). There was no
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26 229 difference between the thin chips and slices but drying thick chips resulted in significantly
27
28 230 higher loss than the other chipping methods, respectively 14.6% for thick chips and 10.7% for
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30 231 thin chips; 9.3% for traditional slices ($p < 0.01$) (Table 3). Greater losses of total carotenoids in
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32 232 thick chips compared to thin chips could be explained by inadequate chip size: with a small
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34 233 surface area to volume ratio, thick chips may have evacuated moisture less efficiently and the
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36 234 core of the chips may have been less protected during drying. Longer drying times were
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38 235 associated with greater losses of carotenoids during drying of sweet potato (Bechoff *et al.*
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40 236 2007). Bechoff *et al.* (2009) working on OFSP also reported that surface area of chip resulted
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42 237 in differential carotenoid loss in sun-drying. In the drying of carrots Wang & Xi (2005)
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44 238 reported that β -carotene degradation increased with sample thickness and was also linked to
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46 239 moisture content reached. In the case of slices, reasons might have been different. Greater
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48 240 losses of total carotenoids in thick chips compared to slices could be explained by the greater
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50 241 damage of tissues due to mechanical chipping as opposed to manual slicing. More
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52 242 investigation is still needed to understand the relationships between chip surface/volume,
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54 243 moisture evacuation and carotenoid loss during drying.
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3 244 Effect of variety on total carotenoid loss after drying
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5 245 Sweet potato variety had a significant impact on total carotenoid loss ($p < 0.01$). Resisto, with a
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7 246 dry matter content of 27.0%, lost more carotenoids (mean loss of 13.2%) than MGCL01 with
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10 247 a dry matter of 35.4% (mean loss of 5.2%) (Table 1). A similar trend of higher dry matter
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12 248 varieties being associated with lower carotenoid losses was reported by Bechoff *et al.* (2010a)
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14
15 249 in on-station trials with six OFSP varieties. This difference between losses in Resisto and
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17 250 MGCL01 varieties might result from difference between dry matter contents that would
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19 251 influence the drying process.
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24 253 Effect of chipping on total carotenoid loss during storage
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27 254 Overall average losses in carotenoids from stored chips and slices after one month; two and
28
29 255 four months of storage are presented in Figure 1. No effect of chipping was reported when
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31 256 analysing thin, thick chips and slices during storage (ANOVA; $p < 0.01$). The lack of
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33 257 interaction between chipping and storage time confirmed that there was consistently no effect
34
35 258 of chipping throughout the storage period. Working on pure β -carotene encapsulated in
36
37 259 dextrose equivalent maltodextrin by three drying processes: spray, drum and freeze drying,
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39 260 Desorby *et al.* (1997) found that larger particles obtained in drum drying had improved β -
40
41 261 carotene stability over storage when compared with the other processes. Mills & Hart (1945)
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43 262 working on dehydrated sweet potato also found that six month-stored flour had higher
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45 263 carotene loss than sliced material at ambient temperature and concluded that sweet potato
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47 264 should be stored in the way they are dehydrated rather than milled into flour. In the present
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49 265 study, the lack of difference from chipping, however, did not agree with the results by
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51 266 Desorby *et al.* (1997) and Mills & Hart (1945), but it is believed that the difference in
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53 267 retention observed in these previous studies is a result of the very different particle sizes of
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55 268 samples tested (*i.e.* flour and slices) that may have resulted in differential porosity to air
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3 269 oxidation. This present study demonstrated that there was no effect of chip size in stored
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6 270 samples. Oxidation is reported as the main factor responsible for carotenoid degradation
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8 271 during storage of dried sweet potato (Emenhiser *et al.*, 1999). Therefore the lack of
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10 272 differences in this study is hypothesised to result from similar air oxygen diffusion through
11
12 273 the different chip/slice sizes (that did not differ as much in size as with flour and slices) of the
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15 274 samples stored in jute bags.
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18 276 Effect of variety on total carotenoid loss during storage

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20 277 There was a significant effect of variety during storage of dried sweet potato ($p < 0.01$). Resisto
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22 278 with 26.8%, 47.8%, 78.6% loss after one month, two and four months of storage, had lower
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24 279 total carotenoid losses than the MGCL01 variety with 39.0%, 63.2%, 87.7% respectively
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26
27 280 (Figure 1). This could possibly result from differential composition in other constituents that
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29 281 can enhance or delay carotenoid degradation: for instance, enhancers could be unsaturated
30
31 282 fatty acids that are mostly linoleic and linolenic acids in sweet potato (Walter & Purcell,
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33 283 1974) and were related to lipid peroxidation (Arya *et al.*, 1979), and inhibitors of carotenoid
34
35 284 oxidation could be phenolic compounds. Phenolic content has been positively correlated to
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37 285 antioxidant activity in various sweet potato varieties (Teow *et al.*, 2007). More investigation
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39 286 is required to understand varietal differences with regard to carotenoid retention.
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47 288 Estimation of vitamin A activity in chips after drying and storage

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49 289 Immediately after drying, average total carotenoid contents for Resisto and MGCL01
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51 290 respectively were $355.6 \mu\text{g}\cdot\text{g}^{-1}$ and $218.2 \mu\text{g}\cdot\text{g}^{-1}$ on a dry weight basis. According to Bechoff
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53 291 *et al.* (2010a), these values corresponded to an estimated vitamin A activity of 24 617 and 15
54
55 292 $107 \text{ RE}\cdot\text{kg}^{-1}$ respectively and were largely beyond the recommended daily allowance for
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57 293 children ($4000 \text{ RE}\cdot\text{kg}^{-1}$). After a four month-storage, average total carotenoid contents for
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3 294 Resisto and MGCL01 were $73.4 \mu\text{g}\cdot\text{g}^{-1}$ and $25.9 \mu\text{g}\cdot\text{g}^{-1}$ on a dry weight basis respectively.
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5 295 These values corresponded to an estimated vitamin A activity of 5080 and $1796 \text{ RE}\cdot\text{kg}^{-1}$
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7
8 296 respectively. After four month-storage the vitamin A activity is strongly reduced and only
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10 297 Resisto variety meets the RDA. However because of other quality issues (*i.e.* presence of
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12 298 insects) the recommended storage period should not exceed 3 months for Resisto. In order to
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14
15 299 meet the RDA, the storage time for MGCL01 should not be over two months. These estimates
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17 300 however do not take into account losses occurring during the further processing of dried sweet
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20 301 potato into a form eaten by consumers. This should be the subject of another research study.

21 22 23 302 Identification of carotenoids before and after storage

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26 303 The individual carotenoid compounds before drying, after drying and after 4 month-storage of
27
28 304 dried sweet potato were tentatively identified by HPLC (Figure 2). Resisto had the same
29
30 305 chromatographic profile as MGCL01. Therefore only the chromatograms for Resisto are
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32
33 306 shown. The main compound is *trans*- β -carotene (peak 7) resolved at 37 min. and representing
34
35 307 84% of the total carotenoid concentration, both for Resisto and MGCL01 samples on average
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37 308 (over dried and stored samples). Other peaks were minor compounds mostly degradation
38
39
40 309 products of all-*trans*- β -carotene and even present in fresh root samples in very small
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42
43 310 quantities. The presence of β -carotene 5,6 epoxide has been reported by Kósambo *et al.*
44
45 311 (1998) in fresh sweet potato roots. On average (for dried and stored sliced Resisto variety)
46
47 312 percentages were the followings; β -carotene 5,6-epoxide (4.0%), 5,6-epoxide (3.2%) 9-*cis*
48
49 313 (1.3%) and 13-*cis*- β -carotene (3.1%). *Trans*- β -carotene, β -carotene 5,6-epoxide, 9-*cis* and 13-
50
51
52 314 *cis*- β -carotene were previously identified using the same HPLC system on a different sweet
53
54 315 potato variety (Bechoff *et al.*, 2009). In spite of the degradation of β -carotene, no clear
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56
57 316 increase of degradation products was readily observed using the HPLC technique. There are
58
59 317 minor differences between the chromatographic profiles of those samples, fresh (Figure 2A)
60
318 or dried (Figure 2B) or dried and subsequently stored (Figure 2C): peaks a (possibly β -

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3 319 carotene-5,6,5',6'-diepoxide); b (possibly β -carotene-5,6,5',8'-diepoxide) were found in fresh
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6 320 roots, peaks a, b and c (25 min.unidentified) were found in dried chips but peak c was only
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8 321 detected after four months of storage. Peak 2 (β -carotene 5,6 epoxide) was not affected by
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10 322 drying but was sharply reduced during storage. On the other hand, peaks 3 (β -carotene 5,8
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12 323 epoxide) and 6 (13-cis β -carotene) decreased at a lower rate during storage. Storage affected
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14
15 324 more the chromatographic profile of carotenoids than drying did. Harsher conditions of
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17 325 processing may be necessary to induce more differences in the carotenoid profile. In contrast
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19
20 326 to this study, significant differences in the chromatographic profile of fresh and heated citrus
21
22 327 juices (5h; 95°C) have been described by Dhuique-Mayer *et al.* (2007). The present profile of
23
24 328 carotenoids in OFSP flour showed that there were very few qualitative differences in the
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26
27 329 chromatogram of samples immediately before or after drying, or after storage for 4 months.

30 330 Kinetics of individual carotenoid degradation during storage

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32
33 331 Kinetics of carotenoid loss per variety are presented in Table 4. For trans β -carotene and β -
34
35 332 carotene 5,6-epoxide, the coefficients of correlation with storage time were generally higher
36
37 333 than $R=-0.95$. MGCL01 variety fitted better first order kinetics whilst Resisto fitted equally
38
39
40 334 zero and first order kinetics and this has not been reported previously. Instead, it has been
41
42 335 shown that dried food fitted first order kinetics degradation during storage (Hidalgo &
43
44 336 Brandolini, 2008; Koca *et al.*, 2007). Nevertheless, working on pure β -carotene powder,
45
46
47 337 Mínguez-Mosquera & Jaren-Galan (1995) demonstrated that degradation followed zero-order
48
49 338 kinetics in an organic anhydrous medium while in an aqueous medium it followed first-order
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51
52 339 kinetics. Zero order reactions are found when the substrate is in excess. Because Resisto had
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54 340 twice as much trans- β -carotene as MGCL01 this could possibly explain why the zero order
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57 341 reaction also fitted Resisto. This indicates that the oxidant had no limitation on the substrate
58
59 342 which means that oxygen from the air could easily penetrate the product. There are a few
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343 discrepancies between the two models because in order zero Resisto degradation was faster

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3 344 than MGCL01 and order one the opposite. Because coefficients of correlation were higher in
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5 345 first order, particularly on MGCL01, the first order was considered. First order rates of
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8 346 degradation were 0.0171 day^{-1} for trans- β -carotene on Resisto and 0.0251 day^{-1} on MGCL01.
9
10 347 The rate of degradation of β -carotene 5,6 epoxide was slightly faster than that of trans- β -
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12 348 carotene (0.0249 and 0.0315 day^{-1} on Resisto and MGCL01 respectively) and this was in
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14
15 349 accordance with recent work by Bechoff *et al.* (2010b).
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17 350
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19 351 Isomers of β -carotene, 13-cis- and 9-cis-, degraded following first order kinetics however
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22 352 with coefficients of correlation with storage time lower than trans- β -carotene and 5,6 epoxide-
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24 353 β -carotene ($R \sim 0.80$). Rate constants of 13-cis- and 9-cis isomers in Resisto and MGCL01
25
26 354 being 0.0080 ; 0.0102 and 0.0115 ; 0.0190 day^{-1} respectively were less than that of trans- β -
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28
29 355 carotene (0.0171 and 0.0251 day^{-1}). This observation is significant because, to our knowledge,
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31 356 the rate of degradation of cis-isomers has not been widely reported in literature when working
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34 357 on storage. A degradation of cis-isomers jointly with trans- β -carotene in solar-drying was
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36 358 however reported by Bechoff *et al.* (2009); Kidmose *et al.* (2007); Mulokozi & Svanberg
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38 359 (2003) working on sweet potato drying. In summary, these results showed that the
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41 360 concentration of all the carotenoids was proportionally reduced in storage.
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45 362 **CONCLUSION**
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48 363 Compared to the earlier study carried out on-research station in Uganda (Bechoff *et al.*
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50 364 2010a), retentions of total carotenoids after on-farm drying in Mozambique were similar,
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53 365 when considering the same type of dryers (tunnel or sun dryers). It was shown in both studies
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55 366 that a higher level of technology (tunnel dryer) as compared with a lower level of technology
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58 367 (open air sun drying on raised trays), did not necessarily lead to a higher carotenoid retention.
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3 369 The lack of difference in carotenoid retention between different chip sizes during storage is
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5 370 also positive for farmers, because it means that they can limit their management costs because
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7 371 traditional hand slicing of sweet potato was as good as the use of a mechanical chipper on the
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9 372 retention of carotenoids. On the other hand, the effect of variety was significant in drying and
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11 373 storage. These observations require investigation on more varieties as this was noted in the
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13 374 research station based study (Bechoff *et al.* 2010a).
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20 376 Total carotenoid losses during storage were high and these considered being slightly greater
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22 377 than the losses determined on-station in Uganda (results after four month-storage). Higher
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24 378 losses in the on-farm based study in Mozambique may be explained by higher temperatures
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26 379 and lower relative humidity (Bechoff *et al.*, 2010b) especially in the day. In order to meet a
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28 380 significant part of daily nutritional requirements in provitamin A (100g corresponding to
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30 381 100% of RDA for children) (Bechoff *et al.*, 2010a), chip samples should not be stored for
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32 382 more than two months for MGCL and four months for Resisto. However Resisto chips should
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34 383 preferably not be stored more than three months because of insect damage.
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41 385 It is possible to do on-farm research and to get similar results to that obtained on-research
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43 386 station. These findings are important when transferring technology from a research station,
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45 387 which includes control over research-parameters, to the more realistic situation of the farm
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47 388 where farmers themselves monitor the drying and storage of their crops.
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58
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3 394 with orange fleshed sweetpotatoes in Uganda and Mozambique". The views expressed are
4
5 395 however those of the authors.
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527 **Table 1: Total carotenoid losses after drying influenced by treatment (dryer, chipping)**
 528 **using MGCL01 and Resisto varieties**

Variety	Chipping	Dryer	Dry matter content (%)	Drying time* (h)	Total carotenoid content ($\mu\text{g}\cdot\text{g}^{-1}$ db)**	Total carotenoid loss (%)	
MGCL 01	Fresh roots		35.4		235.6 (6.5) bc	-	
	Thin chips	Tunnel	93.9	25.5	210.2 (5.0) a	10.8	
		Open	92.1	23.8	224.2 (6.0) abc	4.9	
		Shade	89.9	26.5	238.0 (6.2) bc	-1.0***	
	Thick chips	Open	89.6	23.9	224.5 (1.9) abc	4.7	
	Slices	Tunnel	91.4	47.7	204.9 (2.6) a	13.0	
		Open	87.7	47.6	219.4 (3.2) ab	6.9	
		Shade	86.8	50.7	242.5 (6.3) c	-2.9***	
	Resisto	Fresh roots		27.0		434.4 (0.7) e	-
		Thin chips	Tunnel	91.9	26.1	371.1 (2.5) bc	14.6
Open			91.5	25.4	362.8 (13.0) b	16.5	
Shade			89.9	50.7	401.0 (8.3) cd	7.7	
Thick chips		Open	91.0	62.3	327.7 (2.8) a	24.6	
Slices		Tunnel	88.8	72.4	376.2 (4.8) bc	13.4	
		Open	84.0	75.4	383.6 (6.2) bc	11.7	
		Shade	78.3	75.5	418.0 (1.5) de	3.8	

529 * Drying time includes days and nights of samples spent on dryers –average of two-drying trials.

530 ** db: dry weight basis. Each value represents the mean (standard deviation) of two extractions for two-drying
 531 trials (2^2). For each sweet potato variety, values followed by different letters are significantly different
 532 (ANOVA-Tukey test; $p < 0.05$). Total carotenoid content was measured using a Hewlett Packard 8452A
 533 spectrophotometer at an absorbance of 450nm.

534 ***Negative values are not significantly different from values in fresh sweet potatoes

535 Average and variation on day/night temperature and humidity respectively were 22°C (12-33°C) and 65% (25-
 536 95%) in ambient conditions; 26°C (11-55°C) and (63% (13-100%) inside the tunnel dryer.

538 **Table 2: Effect of dryer type on carotenoid loss:**

539 **ANOVA (main effects) - Factors: variety: (Resisto, MGCL01); dryer (open, tunnel,**
 540 **shade); chipper (slices, thin chips); replication trial, and final dry matter (after drying)**
 541 **as a covariate**

542

Source	df	Mean square
Variety	1	4.800**
Dryer	2	2.000**
Chipper	1	0.100
Trial	1	0.002
Final dry matter (covariate)	1	0.600*
Error	41	0.100
Total	48	

543 * Significant at $p < 0.05$; ** Significant at $p < 0.01$

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4 545 **Table 3: Effect of chipper on carotenoid loss after open air sun drying:**
5 546 **ANOVA (main effects) - Factors: variety (Resisto, MGCL01); chipper (slices, thick**
6 547 **chips, thin chips); replication trial, and final dry matter as a covariate**
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548

Source	df	Mean Square
Variety	1	11.000**
Chipper	2	1.100**
Trial	1	<0.001
Final dry matter (covariate)	1	2.900**
Error	18	0.100
Total	23	

549 ** Significant at $p < 0.01$

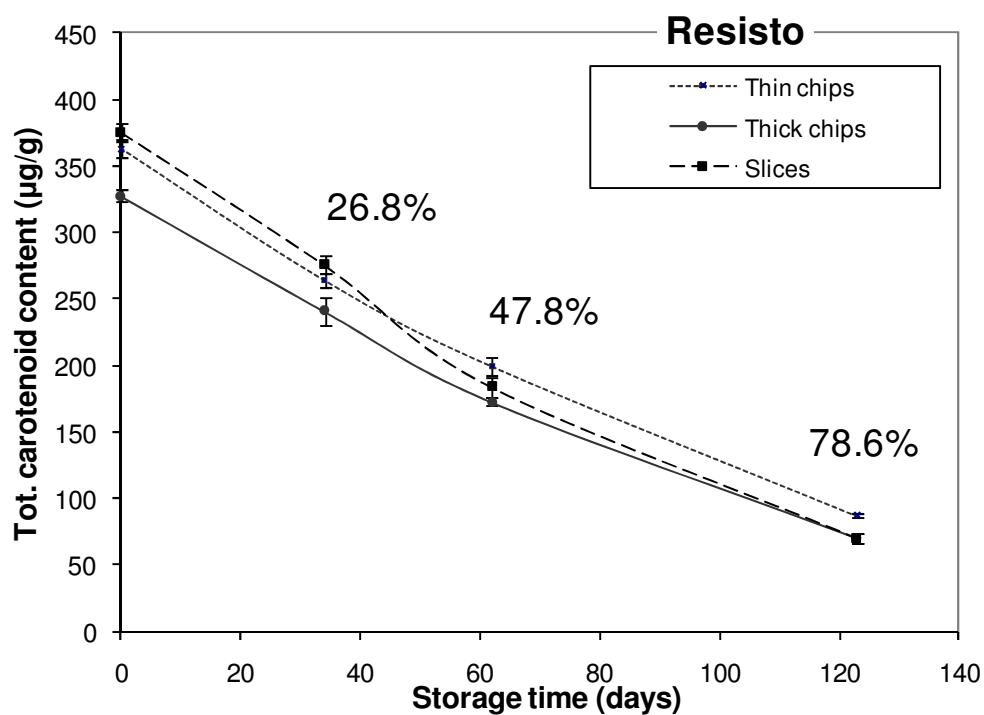
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551 **Table 4: Kinetic parameters of zero order and first order carotenoid degradation in**
 552 **Resisto and MGCL01 slices stored for four months**
 553

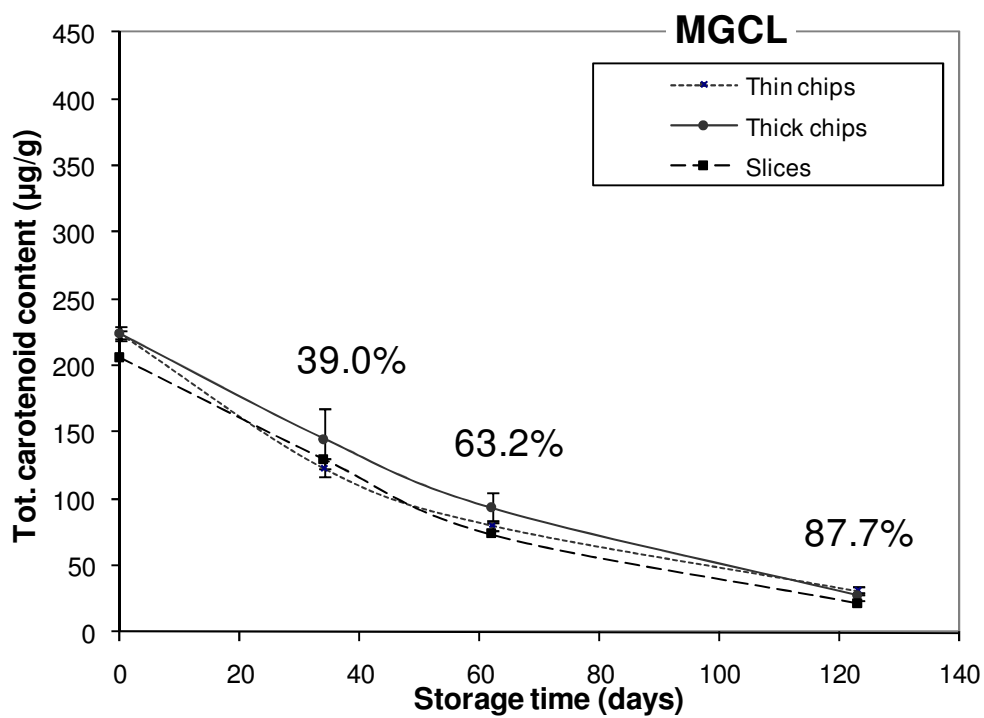
	Reaction Order	Trans- β -carotene		5,6 epoxide- β -carotene		13-cis- β -carotene		9-cis- β -carotene	
		k (day ⁻¹)	R	k (day ⁻¹)	R	k (day ⁻¹)	R	k (day ⁻¹)	R
Resisto	0	2.7643 (0.2500)	-0.976	0.1840 (0.0131)	-0.985	0.0376 (0.0054)	-0.943	0.0228 (0.0046)	-0.896
	1	0.0171 (0.0010)	-0.990	0.0249 (0.0025)	-0.971	0.0080 (0.0009)	-0.963	0.0102 (0.0012)	-0.963
MGCL 01	0	1.5436 (0.2648)	-0.922	0.0989 (0.0144)	-0.942	0.0261 (0.0081)	-0.796	0.0180 (0.0057)	-0.791
	1	0.0251 (0.0028)	-0.966	0.0315 (0.0035)	-0.965	0.0115 (0.0033)	-0.819	0.0190 (0.0039)	-0.893

554 Each value represents the mean (standard deviation) of two extractions
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Figure 1: Kinetics of total carotenoid degradation during storage of Resisto and MGCL01 varieties chipped to three different sizes. Mean of 2² replicate; error bars refer to standard error.

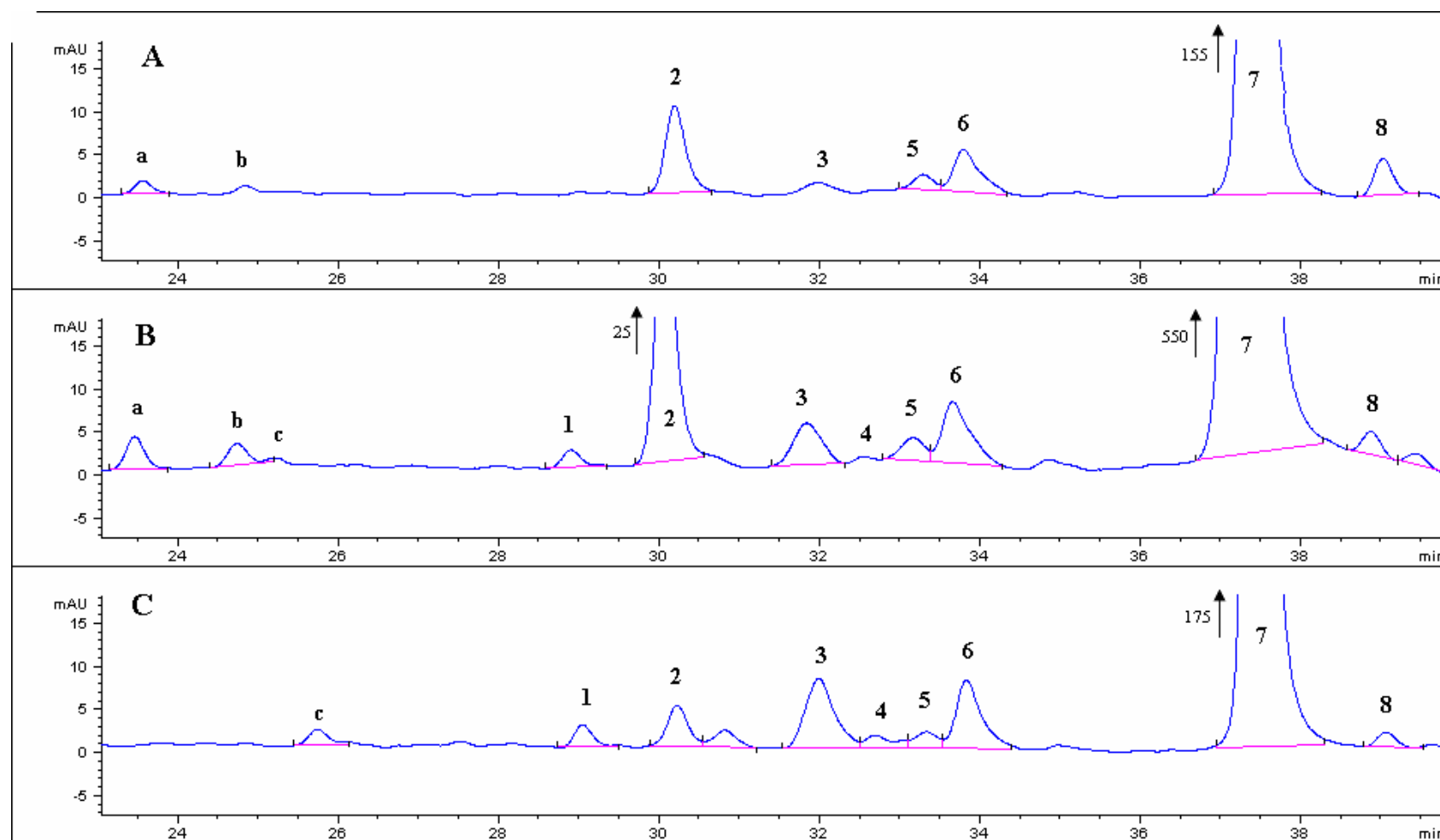


Figure 2: HPLC chromatograms at 450nm of the carotenoids of Resisto slices before drying (A), after drying (B) and after 120 days storage (C). a: Possibly β -carotene-5,6,5',6'-diepoxide (23 min.) (414; **440**; 468nm); b: Possibly β -carotene-5,6,5',8'-diepoxide (24 min.) (400; **422**; 450nm); c: unidentified (25 min.) (406; **424**; 450nm); 1: Possibly 13-cis- β -carotene-5,6 epoxide (29min.) (main wavelengths: 416; **439**; 476nm); 2: Possibly β -carotene-5,6 epoxide (30min.) (422;**446**; 472nm); 3: Possibly β -carotene-5,8 epoxide (32min.) (406;**428**; 452nm); 4&5: Unidentified; 6:13-cis β -carotene (34min.) (338;422;**444**; 472nm); 7: All-trans- β -carotene (37min.) (**452**; 478nm); 8: Possibly 9 cis- β -carotene (39min.) (**446**; 472nm). The three graphs are not to the same scale because of differing dry matter contents (respectively 27%, 89% and 87%). The graphs have been scaled to illustrate the minor peaks and therefore the larger peaks have been truncated.

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2 1 **On-farm evaluation of the impact of drying and storage on the**
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4 2 **carotenoid content of orange-fleshed sweet potato (*Ipomea batata***
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6 3 **Lam.)**

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8
9 4 **Running head: On-farm carotenoid loss in sweet potato chips**

10 5
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12
13 6 Aurélie Bechoff^{1*}, Keith Tomlins¹, Claudie Dhuique-Mayer², Richard Dove³ and
14
15 7 Andrew Westby¹

16
17 8 ¹Natural Resources Institute, University of Greenwich, Central Avenue, Chatham Maritime,
18
19 9 Kent ME4 4TB, United Kingdom.

20
21 10 ²Centre International de Recherche Agronomique pour le Développement (CIRAD) UMR
22
23 11 Qualisud, TA 95B/16, 34398 Montpellier, France

24
25 12 ³HarvestPlus Reaching End Users Project, World Vision, CP 517, Rua de Resistencia,
26
27 13 Quelimane, Mozambique

28
29 14 *Correspondence to: Aurelie Bechoff, Natural Resources Institute (NRI), University of
30
31 15 Greenwich, Central Avenue, Chatham, Kent ME4 4TB, UK. Email: a.bechoff@gre.ac.uk

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33 16
34 17 **Abstract:** Drying of orange-fleshed sweet potato was evaluated under African rural
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36 18 conditions. Three locally-built dryers (open air-sun; tunnel and shade) were tested using
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38 19 Resisto and MGCL01 varieties in Mozambique. Total carotenoid losses were low in all dryers
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40 20 being 9.2% on average. After drying sweet potato chips were stored in a traditional way (jute
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42 21 bags inside a mud house). Chip size (thin, thick chip or slice) had a significant effect on
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44 22 drying ($p < 0.05$) but not on storage; and variety had an effect on both. Total carotenoid losses
45
46 23 during storage were much higher being 83.7% on average, after four months, with main
47
48 24 individual carotenoids fitting a first order kinetics degradation. Globally carotenoid losses on-
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50 25 farm or on-research station, were of similar level.

1
2 26 **Keywords:** *Ipomea batata* (L.) Lam, carotenoids, storage, drying, on-farm, on-research.
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5
6 28 **INTRODUCTION**
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8 29 Mozambique is one of the poorest countries in the world, and additionally, one of the most
9
10 30 affected by vitamin A deficiency; 71% of the children under five are deficient (Aguayo &
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12 31 Baker, 2005). White-fleshed sweet potato (WFSP) is traditionally part of the Mozambican
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14 32 diet, as a source of carbohydrate. An integrated agricultural and nutritional intervention
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16 33 involving households with young children in rural areas of Mozambique has demonstrated
17
18 34 that regular consumption of orange-fleshed sweet potato (OFSP), rich in β -carotene,
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20 35 significantly improved the vitamin A status of the children (Low *et al.*, 2007). The marketing
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22 36 and consumption of OFSP in Mozambique has increased as a result of initiatives by Centro
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24 37 Internacional de la Papa (CIP) and Instituto de Investigação Agrária de Moçambique (IAAM),
25
26 38 and recent promotion programmes, such as the HarvestPlus Reaching End Users Project
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28 39 (2006-2010). New ways of consuming OFSP in forms such as juice, bread and confectionary
29
30 40 products are being investigated in order to extend the availability and nutritional benefits
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32 41 through both home consumption and trade. The availability of fresh sweet potato is seasonal
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34 42 and storage of the fresh root beyond 3 months is difficult (Tomlins *et al.*, 2007). Hence the
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36 43 production of dried products could potentially extend the availability of sweet potato by up to
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38 44 4-6 months. Sun-drying of sweet potato is a traditional processing practice in many
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40 45 developing countries including a number of African countries (Woolfe, 1992). Although sun-
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42 46 drying of sweet potato has been reported in Mozambique (Dove R., pers. comm.), reports
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44 47 have been scarce. A World Vision survey for OVATA in Zambezia district, Mozambique
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46 48 (van Straaten, 2006) indicated that about 35% of households who grow sweet potato also
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48 49 practiced drying of sweet potato. Sun-drying is a non-controlled technology and previous
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50 50 studies on a range of commodities have demonstrated that the level of drying technology used
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2 51 has an impact on provitamin A carotenoid retention (Bechoff *et al.*, 2009; Chen *et al.*, 2007;
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4 52 Desorby *et al.*, 1997; Mulokozi & Svanberg, 2003; Negi & Roy, 2000). Sun-drying could
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6 53 result in higher carotenoid losses than with other technologies, such as solar-drying
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8 54 (Mulokozi & Svanberg, 2003; Negi & Roy, 2000). However recent publications (Bengtsson *et*
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10 55 *al.*, 2008; Bechoff *et al.*, 2009; Bechoff *et al.*, 2010a) have showed that carotenoid losses
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12 56 from sweet potato chips during sun-drying were low and were similar to solar-drying. In
13
14 57 addition, it was demonstrated in an on-station study in Uganda (Bechoff *et al.*, 2010a), that
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16 58 losses of carotenoids were much more critical during storage for four months (70.4%) than
17
18 59 during drying (9.0%). Tomlins *et al.* (2007) argued that experimental results obtained on a
19
20 60 research station do not necessarily transfer to the farm situation because of variations in
21
22 61 farmer knowledge and the local environment. It was therefore important to verify the on-
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24 62 station results in typical rural setting.

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28 64 In order to better preserve provitamin A in sweet potato drying, there was a further need to
29
30 65 determine whether process variables influence carotenoid degradation and the rate of
31
32 66 degradation during storage. In an on-farm study, variables that can be straightforwardly
33
34 67 explored are sweet potato chip size and variety. In laboratory trials, chip size has been
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36 68 reported to influence carotenoid degradation in sweet potato during sun-drying (Bechoff *et*
37
38 69 *al.*, 2009) and the variety of sweet potato has also been reported to influence carotenoid
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40 70 degradation (Bechoff *et al.*, 2010a). Determination of kinetics of carotenoid degradation in
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42 71 dried sweet potato during storage under laboratory conditions has been reported in literature
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44 72 (Haralampu & Karel, 1983; Stephanovitch & Karel, 1982) but field studies measuring
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46 73 carotenoid kinetics in dried food commodities such as sweet potato are scarce. The
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48 74 determination of carotenoid degradation rate under on-farm conditions could bring a practical

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75 help to farmers and millers with the evaluation of dried OFSP shelf life that could potentially
76 lead to an improvement of the product quality.

77 The aim of the study was to evaluate simple and low-cost drying and storage for orange-
78 fleshed sweet potato (OFSP) on-farm. The main objective was to measure the level of
79 carotenoid loss after solar and sun drying and over a four-month storage period taking into
80 account the effect of variety and chipping.

82 MATERIALS AND METHODS

83 Root samples

84 Mature sweet potato roots (MGCL01 and Resisto varieties), about 80 kg per variety, were
85 purchased from farmers around Lualua, Zambézia Province, Mozambique (105 km from
86 Quelimane, the Province Capital). The exact root harvest age was not known. All roots were
87 processed within one to three days after harvest.

88 Dryers

89 Three dryers were constructed on a farm belonging to a subsistence farmer at Lualua. Apart
90 from the greenhouse clear plastic (Strawberry 3 seasons BPI-VISQUEEN®, UK thickness
91 150 µm), all building materials were obtained locally and constructed by local craftsmen.
92 Each of the dryers was mounted on a simple wooden structure that was fitted with straw mats.
93 - The tunnel dryer had similar dimensions to the on-research station dryer in Uganda (Bechoff
94 *et al.*, 2010a). It had a total length of 9 m and a width of 1.5 m. The collector (absorber)
95 occupied the first 3.5 m and was formed of an iron metal sheet. The rest of the dryer (5.5 m)
96 was used as drying area. The floor of the drying area was made of straw mats covered with
97 black plastic sheeting to insulate the structure. Clear greenhouse plastic covered the whole

1
2 98 structure apart from the inlet and outlet allowing air flow and protected by mosquito net
3
4 99 (0.55m² each). The dryer had a 6° slope.
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6 100 - The open air dryer (exposed to direct sun) had a length of 6 m and a width of 1.5m with a
7
8 101 height of 0.9m and had a 6° slope.
9
10 102 - The shade dryer was identical to the open air dryer and with the addition of a grass lined
11
12 103 roof. The roof was about 0.6 m larger and longer than the table in order to protect it from sun
13
14 104 light. The shade dryer was flat (*i.e.* without a 6° slope) because of building constraints.
15
16 105 - Each dryer could fit 6 trays of 4 kg fresh sample each and surface area per tray was 1.03m².
17
18 106 The geographical position of the dryers was determined using GPS (GPS 60, GARMIN®).
19
20 107 Dryers were positioned facing north; this allowed maximum sun exposure in the southern
21
22 108 hemisphere. Temperature/humidity dataloggers (Tinytalk 2 Geminidatalogger, Chichester,
23
24 109 UK) were placed in the tunnel dryer and under the shade for ambient temperature
25
26 110 measurement.

28 111 Drying

30 112 Drying trials were carried out in duplicate on different days (one day and three days after
31
32 113 harvest). Roots were washed and spread on a black plastic under the shade for draining. Five
33
34 114 fresh roots per variety were collected for carotenoid analysis. On the drying day, unpeeled
35
36 115 roots were chipped using either a mechanical rotary disc chipper producing either thick and
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38 116 thin chips, or were hand-sliced (traditional way). Size (thickness, width, length) of ten fresh
39
40 117 chips or slices was recorded using a digital calliper. Samples (4 kg) were weighed (Hanson
41
42 118 Electronic Chrome Effect Scale; ±1 g) after careful mixing (using a quartering technique). All
43
44 119 preparation operations were carried out in the shade to minimize losses in carotenoids. Sweet
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46 120 potato samples were evenly spread on mosquito mesh trays (6 trays per dryer) at a density of
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48 121 3.9 kg.m⁻². Loading time was recorded for each dryer. Samples were weighed and turned
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50 122 frequently during drying. Samples were left overnight in the dryers because rain was unlikely
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2 123 at the time of the study. Under these field conditions, the end of drying was evaluated
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4 124 subjectively by the presence of flour and a characteristic cracking noise when crushed in the
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6 125 hand. The fresh samples of chips/slices per treatment with an initial weight of 4 kg (per
7
8 126 sample) reached a final weight of 1.5 kg for MGCL01 and 1.0 kg for Resisto after drying.
9

10 127 Collection of dried sweet potato chips for analysis and storage

11 128 A carefully mixed portion of dried chips/slices (about 200 g) was collected in zip-polythene
12
13 129 bags and placed in a cooler bag before they were transported (within a couple of hours) to a
14
15 130 freezer (-20 °C) in Quelimane. The remainder of the chips/slices were used for the storage
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17 131 study (at ambient temperature). Samples were stored in traditional bags made of jute and hung
18
19 132 inside a house constructed from mud in Lualua. In order to measure losses during storage,
20
21 133 sub-samples (200 g chips or slices per stored sample) were removed respectively after 1
22
23 134 month (31 days), 2 months (62 days) and 4 months (125 days) and placed in polythene bags in
24
25 135 a cooler bag and quickly transferred and stored in the freezer. The datalogger recording the
26
27 136 ambient temperature during storage was unfortunately lost, but it is estimated from records
28
29 137 taken nearby in Quelimane that the temperature in the mud house was on average 25 °C with
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31 138 minimum/maximum temperatures of 20/31 °C (Weather Underground Quelimane, 2007).
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34 139 Carotenoid analysis

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37 140 Chip samples in zip bags were stored at -20°C for 1-6 months before analysis because of
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39 141 delays and the low sample throughput for this method. No significant carotenoid loss was
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41 142 observed on chips in freezer in this interval ($p < 0.05$) (Bechoff 2010). Samples were milled
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43 143 into flour (particle sizes of less than 1 mm) using a Laboratory mill 3600 (Perten Instruments,
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45 144 Segeltorp, Sweden) and extracted in duplicate in a randomised order. Carotenoids were
46
47 145 identified and quantified using the method described by Bechoff *et al.* (2010b). The extraction
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49 146 stage was adapted from Rodriguez-Amaya and Kimura (2004). A portion of the homogeneous
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2 147 representative sample (0.4-2.0 g of flour) was re-hydrated for 20 min in 10 ml deionised
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4 148 water, homogenised with 50mL methanol:tetrahydrofuran (THF) (1:1) for 1 minute and
5
6 149 filtered. The homogenised extract was rinsed with methanol:THF (1:1) until there was no
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8 150 yellow colour left in the filtrate. Partition between the aqueous phase and organic phase
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10 151 containing the carotenoids was achieved by addition of petroleum ether (PE -40-60° C). The
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12 152 PE phase was further washed with water, dried by addition of anhydrous sodium sulphate,
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14 153 then filtered and made up to volume (50 ml). For the determination of total carotenoid
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16 154 content, absorbance was measured at 450 nm using a diode array Hewlett Packard 8452A
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18 155 spectrophotometer. For the determination of individual carotenoids by HPLC, the carotenoid
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20 156 extracts in PE were dried by flushing with nitrogen in a dry block system at 35° C. The
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22 157 extracts were dissolved in 1 ml dichloromethane:MTBE (methyl tert-butyl ether): methanol
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24 158 50:40:10. Reverse-phase high performance liquid chromatography using an Agilent 1100
25
26 159 system (Massy, France) was used following the method of Dhuique-Mayer *et al.* (2007).
27
28 160 Carotenoids were separated through a C₃₀ reverse phase column (250 x 4.6 mm i.d.) packed
29
30 161 with 5µm YMC (EUROP GmbH, Germany) at a flow rate of 1 ml.min⁻¹, a column
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32 162 temperature at 25° C and an injection volume of 20 µl. Concentrations were determined by
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34 163 comparison to a standard curve using pure β- carotene ([Extrasynthese, Genay, France](#)).
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38 165 Dry matter determination

40 166 Samples were collected for dry matter determination, before and after drying at the same time
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42 167 as for carotenoids analysis. Determinations were made by drying triplicate 5 g samples at 105
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44 168 °C to constant weight (minimum 24h) (AOAC, 1984).
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2 169 Statistical analyses and calculation of carotenoid degradation rates
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4 170 Normality of sample distribution was tested using Shapiro-Wilk and Kolmogorov Smirnov
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6 171 tests ($p < 0.05$). Analysis of variance (ANOVA) was carried out to determine whether there
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8 172 were significant differences between samples with one up to four factors. A significant
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10 173 difference between samples was determined by a Tukey test. Data were processed on SPSS
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12 174 15.00 (SPSS UK Ltd. Woking, Surrey, UK) for Windows software.

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16 176 Linear regression (on Excel) was used to determine the rate of degradation k following the
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18 177 formula $C = C_0 - kt$ (zero order kinetics) or $\ln C = \ln C_0 - kt$ (first order kinetics) where C_0
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20 178 is the total carotenoid content after drying ($\mu\text{g}\cdot\text{g}^{-1}$); C the total carotenoid content at storage
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22 179 time t ($\mu\text{g}\cdot\text{g}^{-1}$); k the rate constant (days^{-1}) and t the storage time (days).

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25 26 181 **RESULTS AND DISCUSSION**

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29 30 183 **Effect of dryer on total carotenoid loss**

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32 184 Independently of the dryer or variety, average total carotenoid loss during drying was 9.2%.

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34 185 In all cases, levels of loss were less than 24.6% (Table 1). Effect of different factors (new
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36 186 chipper and traditional slicing) and three dryers (shade; sun; tunnel) on the two varieties was
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38 187 evaluated on total carotenoid losses (Table 2). The type of dryer had a significant effect
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40 188 ($p < 0.01$) on total carotenoid loss. Because control over drying was limited in these field
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42 189 conditions, dry matter was included as covariate in the analysis of variance from data
43
44 190 presented in Table 2. The three dryers gave significantly different results of loss: on average
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46 191 there were 13.0%, 10.0% and 1.9% for the tunnel dryer; open air dryer and shade dryer
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48 192 respectively (Table 1). Slight but significantly lower retention of total carotenoids in the
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50 193 tunnel dryer compared to the open air dryer could be explained by the higher temperature

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2 194 during drying (up to 55°C whilst the ambient temperature did not go above 33°C) (Table 1).
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4 195 There was furthermore an issue with moisture evacuation from the product in the tunnel
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6 196 dryer, which is illustrated by the maximum 100% relative humidity reached at night. This
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8 197 may have resulted from a disadvantageous wind direction at this time of the year, blowing
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10 198 East-West, whereas the tunnel was positioned North-South. As compared with the on-station
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12 199 study (Bechoff *et al.*, 2010a) using a similar but optimally oriented tunnel dryer, the on-farm
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14 200 tunnel dryer showed some technical limitations in terms of air flow circulation. In terms of
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16 201 carotenoid losses, the difference in the tunnel and open-air sun dryers (using chips of the same
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18 202 size) was not significant (9.0% for the tunnel and open-air sun dryers in the earlier on-station
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20 203 study) (Bechoff *et al.*, 2010a) and small (13% and 10% respectively working with thin chips
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22 204 in this on-farm study). The tunnel dryer however protected against insects and rain. This type
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24 205 of dryer was mostly designed for experimental use and, because its cost was estimated to be
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26 206 ten times the cost of an open air dryer and five times that of a shade dryer, mainly due to
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28 207 imported materials, it would not be a feasible proposition for Mozambican farmers to adopt.
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30 208 The open air and shade dryer would be the dryers most suited to rural situation in
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32 209 Mozambique because of their improved carotenoid retention, lower cost and availability of
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34 210 most materials locally (on the farm or in the next village).

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2 219 carotenoid retention compared to sun-dried one, while Negi & Roy (2000), working on leafy
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4 220 vegetables, reported that higher carotenoid losses were obtained in shade and sun-drying as
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6 221 opposed to solar (cabinet) drying. These inconsistencies in the literature could be the result
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8 222 from different environmental conditions (temperature, humidity and wind) and different
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10 223 product characteristics influencing carotenoid retention during drying.

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12 225 Effect of chipping on total carotenoid loss after drying

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14 226 Traditional slices, thick and thin chips had an average thickness of about 5.2 mm, 2.9 mm and
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16 227 0.4 mm respectively. The effect of chipping treatment using three chipping treatment is
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18 228 reported in open air drying for both MGCL01 and Resisto varieties (Table 1). There was no
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20 229 difference between the thin chips and slices but drying thick chips resulted in significantly
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22 230 higher loss than the other chipping methods, respectively 14.6% for thick chips and 10.7% for
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24 231 thin chips; 9.3% for traditional slices ($p < 0.01$) (Table 3). Greater losses of total carotenoids in
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26 232 thick chips compared to thin chips could be explained by inadequate chip size: with a small
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28 233 surface area to volume ratio, thick chips may have evacuated moisture less efficiently and the
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30 234 core of the chips may have been less protected during drying. Longer drying times were
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32 235 associated with greater losses of carotenoids during drying of sweet potato (Bechoff *et al.*
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34 236 2007). Bechoff *et al.* (2009) working on OFSP also reported that surface area of chip resulted
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36 237 in differential carotenoid loss in sun-drying. In the drying of carrots Wang & Xi (2005)
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38 238 reported that β -carotene degradation increased with sample thickness and was also linked to
39
40 239 moisture content reached. In the case of slices, reasons might have been different. Greater
41
42 240 losses of total carotenoids in thick chips compared to slices could be explained by the greater
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44 241 damage of tissues due to mechanical chipping as opposed to manual slicing. More
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46 242 investigation is still needed to understand the relationships between chip surface/volume,
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48 243 moisture evacuation and carotenoid loss during drying.

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Effect of variety on total carotenoid loss after drying

Sweet potato variety had a significant impact on total carotenoid loss ($p < 0.01$). Resisto, with a dry matter content of 27.0%, lost more carotenoids (mean loss of 13.2%) than MGCL01 with a dry matter of 35.4% (mean loss of 5.2%) (Table 1). A similar trend of higher dry matter varieties being associated with lower carotenoid losses was reported by Bechoff *et al.* (2010a) in on-station trials with six OFSP varieties. This difference between losses in Resisto and MGCL01 varieties might result from difference between dry matter contents that would influence the drying process.

Effect of chipping on total carotenoid loss during storage

Overall average losses in carotenoids from stored chips and slices after one month; two and four months of storage are presented in Figure 1. No effect of chipping was reported when analysing thin, thick chips and slices during storage (ANOVA; $p < 0.01$). The lack of interaction between chipping and storage time confirmed that there was consistently no effect of chipping throughout the storage period. Working on pure β -carotene encapsulated in dextrose equivalent maltodextrin by three drying processes: spray, drum and freeze drying, Desorby *et al.* (1997) found that larger particles obtained in drum drying had improved β -carotene stability over storage when compared with the other processes. Mills & Hart (1945) working on dehydrated sweet potato also found that six month-stored flour had higher carotene loss than sliced material at ambient temperature and concluded that sweet potato should be stored in the way they are dehydrated rather than milled into flour. In the present study, the lack of difference from chipping, however, did not agree with the results by Desorby *et al.* (1997) and Mills & Hart (1945), but it is believed that the difference in retention observed in these previous studies is a result of the very different particle sizes of samples tested (*i.e.* flour and slices) that may have resulted in differential porosity to air

Deleted: In this study, a new finding was that there was a major varietal effect associated to chipping ($p < 0.01$). (Table 3); total carotenoid loss was on average 17.6% on Resisto and 5.5% on MGCL01. Resisto chips produced by thick chipper were sticky and took a long time to dry (62.3h). The combined effect did not exist when dry matter was included as covariate in the analysis of variance (Table 3). Therefore the higher sensitivity of Resisto to the chipping type compared to MGCL01 can be explained by its lower initial dry matter content that requires evacuating more moisture during drying and is in agreement with Bechoff *et al.* (2010a); Hagenimana *et al.* (1999). ¶

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2 269 oxidation. This present study demonstrated that there was no effect of chip size in stored
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4 270 samples. Oxidation is reported as the main factor responsible for carotenoid degradation
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6 271 during storage of dried sweet potato (Emenhiser *et al.*, 1999). Therefore the lack of
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8 272 differences in this study is hypothesised to result from similar air oxygen diffusion through
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10 273 the different chip/slice sizes (that did not differ as much in size as with flour and slices) of the
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12 274 samples stored in jute bags.

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14 275 15 16 276 Effect of variety on total carotenoid loss during storage

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18 277 There was a significant effect of variety during storage of dried sweet potato ($p < 0.01$). Resisto
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20 278 with 26.8%, 47.8%, 78.6% loss after one month, two and four months of storage, had lower
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22 279 total carotenoid losses than the MGCL01 variety with 39.0%, 63.2%, 87.7% respectively
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24 280 (Figure 1). This could possibly result from differential composition in other constituents that
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26 281 can enhance or delay carotenoid degradation: for instance, enhancers could be unsaturated
27
28 282 fatty acids that are mostly linoleic and linolenic acids in sweet potato (Walter & Purcell,
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30 283 1974) and were related to lipid peroxidation (Arya *et al.*, 1979), and inhibitors of carotenoid
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32 284 oxidation could be phenolic compounds. Phenolic content has been positively correlated to
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34 285 antioxidant activity in various sweet potato varieties (Teow *et al.*, 2007). More investigation
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36 286 is required to understand varietal differences with regard to carotenoid retention.

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38 287 39 288 Estimation of vitamin A activity in chips after drying and storage

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41 289 Immediately after drying, average total carotenoid contents for Resisto and MGCL01
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43 290 respectively were $355.6 \mu\text{g}\cdot\text{g}^{-1}$ and $218.2 \mu\text{g}\cdot\text{g}^{-1}$ on a dry weight basis. According to Bechoff
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45 291 *et al.* (2010a), these values corresponded to an estimated vitamin A activity of 24 617 and 15
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47 292 $107 \text{ RE}\cdot\text{kg}^{-1}$ respectively and were largely beyond the recommended daily allowance for
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49 293 children ($4000 \text{ RE}\cdot\text{kg}^{-1}$). After a four month-storage, average total carotenoid contents for

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2 294 Resisto and MGCL01 were $73.4 \mu\text{g.g}^{-1}$ and $25.9 \mu\text{g.g}^{-1}$ on a dry weight basis respectively.
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4 295 These values corresponded to an estimated vitamin A activity of 5080 and 1796 RE.kg^{-1}
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6 296 respectively. After four month-storage the vitamin A activity is strongly reduced and only
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8 297 Resisto variety meets the RDA. However because of other quality issues (*i.e.* presence of
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10 298 insects) the recommended storage period should not exceed 3 months for Resisto. In order to
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12 299 meet the RDA, the storage time for MGCL01 should not be over two months. These estimates
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14 300 however do not take into account losses occurring during the further processing of dried sweet
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16 301 potato into a form eaten by consumers. This should be the subject of another research study.
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18 19 302 Identification of carotenoids before and after storage

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21 303 The individual carotenoid compounds before drying, after drying and after 4 month-storage of
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23 304 dried sweet potato were tentatively identified by HPLC (Figure 2). Resisto had the same
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25 305 chromatographic profile as MGCL01. Therefore only the chromatograms for Resisto are
26
27 306 shown. The main compound is trans- β -carotene (peak 7) resolved at 37 min. and representing
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29 307 84% of the total carotenoid concentration, both for Resisto and MGCL01 samples on average
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31 308 (over dried and stored samples). Other peaks were minor compounds mostly degradation
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33 309 products of all-trans- β -carotene and even present in fresh root samples in very small
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35 310 quantities. The presence of β -carotene 5,6 epoxide has been reported by Kósambo *et al.*
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37 311 (1998) in fresh sweet potato roots. On average (for dried and stored sliced Resisto variety)
38
39 312 percentages were the followings; β -carotene 5,6-epoxide (4.0%), 5,6-epoxide (3.2%) 9-cis
40
41 313 (1.3%) and 13-cis- β -carotene (3.1%). Trans- β -carotene, β -carotene 5,6-epoxide, 9-cis and 13-
42
43 314 cis- β -carotene were previously identified using the same HPLC system on a different sweet
44
45 315 potato variety (Bechoff *et al.*, 2009). In spite of the degradation of β -carotene, no clear
46
47 316 increase of degradation products was readily observed using the HPLC technique. There are
48
49 317 minor differences between the chromatographic profiles of those samples, fresh (Figure 2A)
50
51 318 or dried (Figure 2B) or dried and subsequently stored (Figure 2C): peaks a (possibly β -
52

1
2 319 carotene-5,6,5',6'-diepoxide); b (possibly β -carotene-5,6,5',8'-diepoxide) were found in fresh
3
4 320 roots, peaks a, b and c (25 min. unidentified) were found in dried chips but peak c was only
5
6 321 detected after four months of storage. Peak 2 (β -carotene 5,6 epoxide) was not affected by
7
8 322 drying but was sharply reduced during storage. On the other hand, peaks 3 (β -carotene 5,8
9
10 323 epoxide) and 6 (13-cis β -carotene) decreased at a lower rate during storage. Storage affected
11
12 324 more the chromatographic profile of carotenoids than drying did. Harsher conditions of
13
14 325 processing may be necessary to induce more differences in the carotenoid profile. In contrast
15
16 326 to this study, significant differences in the chromatographic profile of fresh and heated citrus
17
18 327 juices (5h; 95°C) have been described by Dhuique-Mayer *et al.* (2007). The present profile of
19
20 328 carotenoids in OFSP flour showed that there were very few qualitative differences in the
21
22 329 chromatogram of samples immediately before or after drying, or after storage for 4 months.
23

24 25 330 Kinetics of individual carotenoid degradation during storage

26
27 331 Kinetics of carotenoid loss per variety are presented in Table 4. For trans β -carotene and β -
28
29 332 carotene 5,6-epoxide, the coefficients of correlation with storage time were generally higher
30
31 333 than $R=0.95$. MGCL01 variety fitted better first order kinetics whilst Resisto fitted equally
32
33 334 zero and first order kinetics and this has not been reported previously. Instead, it has been
34
35 335 shown that dried food fitted first order kinetics degradation during storage (Hidalgo &
36
37 336 Brandolini, 2008; Koca *et al.*, 2007). Nevertheless, working on pure β -carotene powder,
38
39 337 Minguez-Mosquera & Jaren-Galan (1995) demonstrated that degradation followed zero-order
40
41 338 kinetics in an organic anhydrous medium while in an aqueous medium it followed first-order
42
43 339 kinetics. Zero order reactions are found when the substrate is in excess. Because Resisto had
44
45 340 twice as much trans- β -carotene as MGCL01 this could possibly explain why the zero order
46
47 341 reaction also fitted Resisto. This indicates that the oxidant had no limitation on the substrate
48
49 342 which means that oxygen from the air could easily penetrate the product. There are a few
50
51 343 discrepancies between the two models because in order zero Resisto degradation was faster
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1
2 344 than MGCL01 and order one the opposite. Because coefficients of correlation were higher in
3
4 345 first order, particularly on MGCL01, the first order was considered. First order rates of
5
6 346 degradation were 0.0171 day^{-1} for trans- β -carotene on Resisto and 0.0251 day^{-1} on MGCL01.
7
8 347 The rate of degradation of β -carotene 5,6 epoxide was slightly faster than that of trans- β -
9
10 348 carotene (0.0249 and 0.0315 day^{-1} on Resisto and MGCL01 respectively) and this was in
11
12 349 accordance with recent work by Bechoff *et al.* (2010b).

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16 351 Isomers of β -carotene, 13-cis- and 9-cis-, degraded following first order kinetics however
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18 352 with coefficients of correlation with storage time lower than trans- β -carotene and 5,6 epoxide-
19
20 353 β -carotene ($R \sim 0.80$). Rate constants of 13-cis- and 9-cis isomers in Resisto and MGCL01
21
22 354 being 0.0080 ; 0.0102 and 0.0115 ; 0.0190 day^{-1} respectively were less than that of trans- β -
23
24 355 carotene (0.0171 and 0.0251 day^{-1}). This observation is significant because, to our knowledge,
25
26 356 the rate of degradation of cis-isomers has not been widely reported in literature when working
27
28 357 on storage. A degradation of cis-isomers jointly with trans- β -carotene in solar-drying was
29
30 358 however reported by Bechoff *et al.* (2009); Kidmose *et al.* (2007); Mulokozi & Svanberg
31
32 359 (2003) working on sweet potato drying. In summary, these results showed that the
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34 360 concentration of all the carotenoids was proportionally reduced in storage.

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36 361
37 362 **CONCLUSION**
38
39 363 Compared to the earlier study carried out on-research station in Uganda (Bechoff *et al.*
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41 364 2010a), retentions of total carotenoids after on-farm drying in Mozambique were similar,
42
43 365 when considering the same type of dryers (tunnel or sun dryers). It was shown in both studies
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45 366 that a higher level of technology (tunnel dryer) as compared with a lower level of technology
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47 367 (open air sun drying on raised trays), did not necessarily lead to a higher carotenoid retention.
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2 369 The lack of difference in carotenoid retention between different chip sizes during storage is
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4 370 also positive for farmers, because it means that they can limit their management costs because
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6 371 traditional hand slicing of sweet potato was as good as the use of a mechanical chipper on the
7
8 372 retention of carotenoids. On the other hand, the effect of variety was significant in drying and
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10 373 storage. These observations require investigation on more varieties as this was noted in the
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12 374 research station based study (Bechoff *et al.* 2010a).

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16 376 Total carotenoid losses during storage were high and these considered being slightly greater
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18 377 than the losses determined on-station in Uganda (results after four month-storage). Higher
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20 378 losses in the on-farm based study in Mozambique may be explained by higher temperatures
21
22 379 and lower relative humidity (Bechoff *et al.*, 2010b) especially in the day. In order to meet a
23
24 380 significant part of daily nutritional requirements in provitamin A (100g corresponding to
25
26 381 100% of RDA for children) (Bechoff *et al.*, 2010a), chip samples should not be stored for
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28 382 more than two months for MGCL and four months for Resisto. However Resisto chips should
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30 383 preferably not be stored more than three months because of insect damage.

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34 385 It is possible to do on-farm research and to get similar results to that obtained on-research
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36 386 station. These findings are important when transferring technology from a research station,
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38 387 which includes control over research-parameters, to the more realistic situation of the farm
39
40 388 where farmers themselves monitor the drying and storage of their crops.

41 389

42 390 **ACKNOWLEDGEMENTS**

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1
2 394 with orange fleshed sweetpotatoes in Uganda and Mozambique". The views expressed are
3
4 395 however those of the authors.
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For Peer Review

527 **Table 1: Total carotenoid losses after drying influenced by treatment (dryer, chipping)**
 528 **using MGCL01 and Resisto varieties**

Variety	Chipping	Dryer	Dry matter content (%)	Drying time* (h)	Total carotenoid content ($\mu\text{g}\cdot\text{g}^{-1}$ db)**	Total carotenoid loss (%)
MGCL 01	Fresh roots		35.4		235.6 (6.5) bc	-
	Thin chips	Tunnel	93.9	25.5	210.2 (5.0) a	10.8
		Open	92.1	23.8	224.2 (6.0) abc	4.9
		Shade	89.9	26.5	238.0 (6.2) bc	-1.0***
	Thick chips	Open	89.6	23.9	224.5 (1.9) abc	4.7
		Tunnel	91.4	47.7	204.9 (2.6) a	13.0
	Slices	Open	87.7	47.6	219.4 (3.2) ab	6.9
		Shade	86.8	50.7	242.5 (6.3) c	-2.9***
		Fresh roots		27.0		434.4 (0.7) e
	Resisto	Thin chips	Tunnel	91.9	26.1	371.1 (2.5) bc
Open			91.5	25.4	362.8 (13.0) b	16.5
Shade			89.9	50.7	401.0 (8.3) cd	7.7
Thick chips		Open	91.0	62.3	327.7 (2.8) a	24.6
		Tunnel	88.8	72.4	376.2 (4.8) bc	13.4
Slices		Open	84.0	75.4	383.6 (6.2) bc	11.7
		Shade	78.3	75.5	418.0 (1.5) de	3.8

* Drying time includes days and nights of samples spent on dryers –average of two-drying trials.

** db: dry weight basis. Each value represents the mean (standard deviation) of two extractions for two-drying trials (2^2). For each sweet potato variety, values followed by different letters are significantly different (ANOVA-Tukey test; $p < 0.05$). Total carotenoid content was measured using a Hewlett Packard 8452A spectrophotometer at an absorbance of 450nm.

***Negative values are not significantly different from values in fresh sweet potatoes

Average and variation on day/night temperature and humidity respectively were 22°C (12-33°C) and 65% (25-95%) in ambient conditions; 26°C (11-55°C) and (63% (13-100%) inside the tunnel dryer.

538 **Table 2: Effect of dryer type on carotenoid loss:**

539 **ANOVA (main effects) - Factors: variety: (Resisto, MGCL01); dryer (open, tunnel,**
 540 **shade); chipper (slices, thin chips); replication trial, and final dry matter (after drying)**
 541 **as a covariate**

542

Source	df	Mean square
Variety	1	<u>4.800**</u>
Dryer	2	<u>2.000**</u>
Chipper	1	<u>0.100</u>
Trial	1	<u>0.002</u>
<u>Final dry matter (covariate)</u>	1	<u>0.600*</u>
Error	41	<u>0.100</u>
Total	48	

543 * Significant at p < 0.05; ** Significant at p < 0.01

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Table 3: Effect of chipper on carotenoid loss after open air sun drying: ANOVA (main effects) - Factors: variety (Resisto, MGCL01); chipper (slices, thick chips, thin chips); replication trial, and final dry matter as a covariate

Source	df	Mean Square
Variety	1	11.000**
Chipper	2	1.100**
Trial	1	<0.001
Final dry matter (covariate)	1	2.900**
Error	18	0.100
Total	23	

** Significant at p < 0.01

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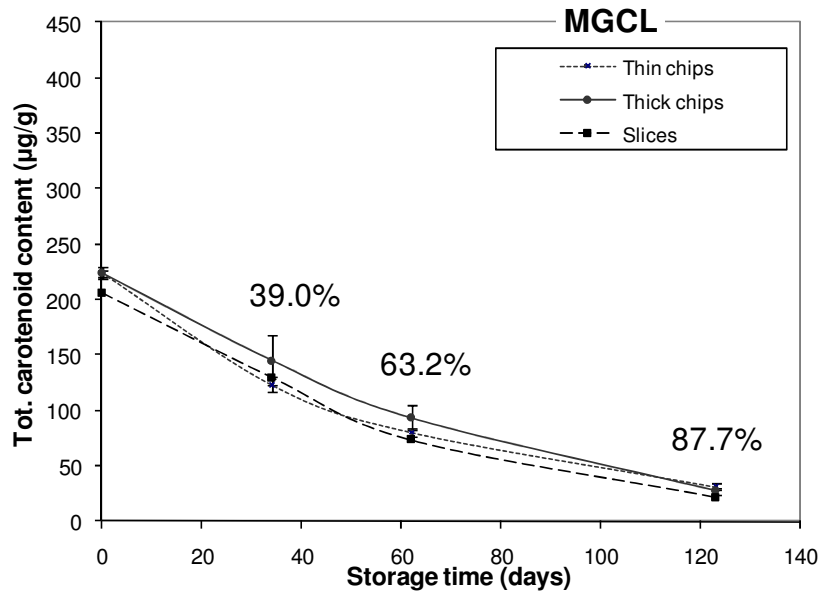
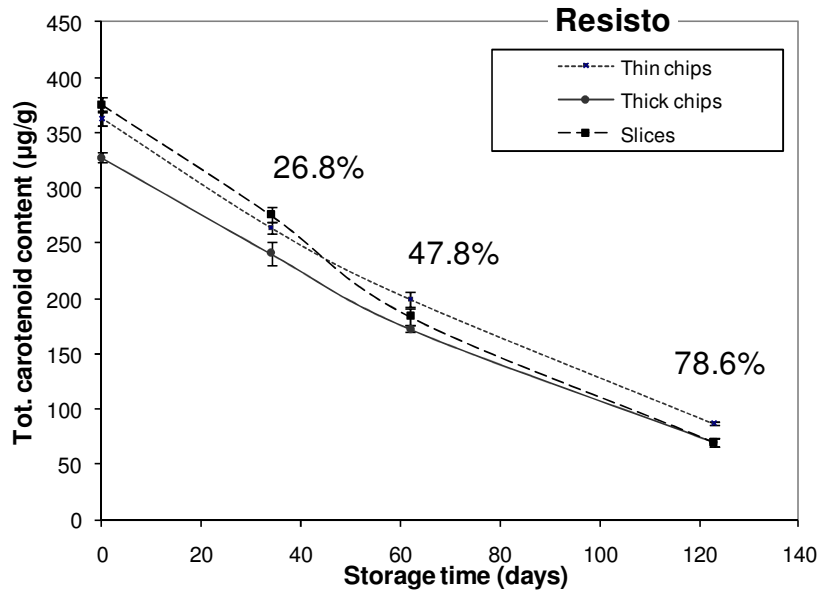
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552 **Table 4: Kinetic parameters of zero order and first order carotenoid degradation in**
 553 **Resisto and MGCL01 slices stored for four months**
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	Reaction Order	Trans- β -carotene		5,6 epoxide- β -carotene		13-cis- β -carotene		9-cis- β -carotene	
		k (day ⁻¹)	R	k (day ⁻¹)	R	k (day ⁻¹)	R	k (day ⁻¹)	R
Resisto	0	2.7643 (0.2500)	-0.976	0.1840 (0.0131)	-0.985	0.0376 (0.0054)	-0.943	0.0228 (0.0046)	-0.896
	1	0.0171 (0.0010)	-0.990	0.0249 (0.0025)	-0.971	0.0080 (0.0009)	-0.963	0.0102 (0.0012)	-0.963
MGCL 01	0	1.5436 (0.2648)	-0.922	0.0989 (0.0144)	-0.942	0.0261 (0.0081)	-0.796	0.0180 (0.0057)	-0.791
	1	0.0251 (0.0028)	-0.966	0.0315 (0.0035)	-0.965	0.0115 (0.0033)	-0.819	0.0190 (0.0039)	-0.893

555 Each value represents the mean (standard deviation) of two extractions
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Figure 1: Kinetics of total carotenoid degradation during storage of Resisto and MGCL01 varieties chipped to three different sizes. Mean of 2² replicate; error bars refer to standard error.

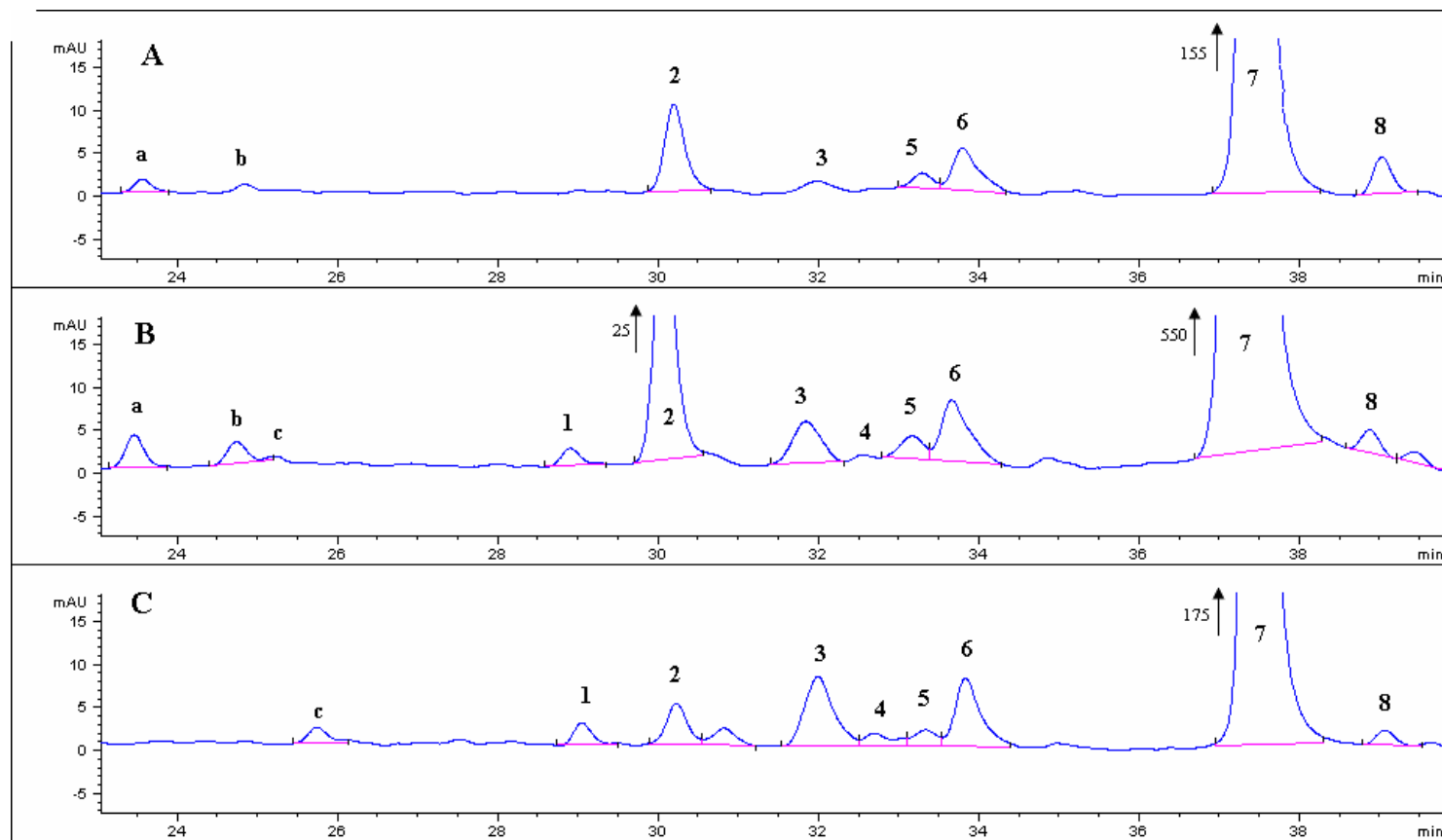


Figure 2: HPLC chromatograms at 450nm of the carotenoids of Resisto slices before drying (A), after drying (B) and after 120 days storage (C). a: Possibly β -carotene-5,6,5',6'-diepoxide (23 min.) (414; **440**; 468nm); b: Possibly β -carotene-5,6,5',8'-diepoxide (24 min.) (400; **422**; 450nm); c: unidentified (25 min.) (406; **424**; 450nm); 1: Possibly 13-cis- β -carotene-5,6 epoxide (29min.) (main wavelengths: 416; **439**; 476nm); 2: Possibly β -carotene-5,6 epoxide (30min.) (422;**446**; 472nm); 3: Possibly β -carotene-5,8 epoxide (32min.) (406;**428**; 452nm); 4&5: Unidentified; 6:13-cis β -carotene (34min.) (338;422;**444**; 472nm); 7: All-trans- β -carotene (37min.) (**452**; 478nm); 8: Possibly 9 cis- β -carotene (39min.) (**446**; 472nm). The three graphs are not to the same scale because of differing dry matter contents (respectively 27%, 89% and 87%). The graphs have been scaled to illustrate the minor peaks and therefore the larger peaks have been truncated.

