International Journal of Food Science +Technology

Editorial

Integrating end-user preferences into breeding programmes for roots, tubers and bananas

Dominique Dufour,[1,2]* Clair Hershey,[3] Bruce R. Hamaker[4] & Jim Lorenzen[5]

1 CIRAD, UMR Qualisud, Montpellier F-34398, France
2 Qualisud, CIRAD, Institut Agro, Univ Montpellier, Avignon Université, Université de La Réunion, Montpellier, France
3 International Consultant, Flinton, PA, USA
4 Whistler Center for Carbohydrate Research Purdue University, West Lafayette, IN, USA
5 Bill & Melinda Gates Foundation, Discovery/Crop R&D Global Growth & Opportunity, Agriculture, Seattle, WA, USA

Summary "*Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding*" special issue, brings together new knowledge about quality traits required for roots, tubers and bananas (RTB) varieties to successfully meet diverse user preferences and expectations, along the variety development and RTB value chains (production, processing, marketing, food preparation, consumption). Key RTB crops in sub-Saharan Africa are cassava, yams, sweetpotatoes, potatoes and bananas/plantains. They are mainly consumed directly as boiled pieces or pounded in the form of smooth, not sticky, and stretchable dough. They are also stewed, steamed or fried. Cassava, the most widely grown RTB, is generally boiled, stewed or steamed in Eastern and Southern Africa, and in West and Central Africa is usually processed directly into derivative products, e.g. whole root fermentation through retting or heap fermentation; fermentation/dewatering of the mash. Biophysical and social knowledge presented in this issue help elaborate goals for both the processing unit operations (food scientist control) and variety traits (breeder control).

In this article, we introduce the key root, tuber and banana (RTB) crops and their derived food products in sub-Saharan Africa (SSA), summarise the goals and methodologies of assessing end-user preferences aimed at breeding suitable varieties and highlight some key findings of the research reported in the special issue – *Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding*. This issue includes 23 original research papers, five review papers and one methodology paper. The authors are affiliated with national research programmes, universities, CGIAR centres (IITA (Nigeria), CIP (Peru) and the Alliance of Bioversity International and CIAT (Colombia)), NRI, CIRAD, NGOs and others. The core contributors present results from the RTBfoods project (*Breeding roots tubers and banana products for end-user preferences* https://rtbfoods.cirad.fr/) and/or the CGIAR Research Program on Roots, Tubers and Bananas https://www.rtb.cgiar.org/. The Bill & Melinda Gates Foundation https://www.gatesfoundation.org/ supports these developments by investing in strategic RTB-related initiatives in SSA. A call for papers by the journal editors elicited an additional six original research papers.

Following a consultation with RTB experts from different backgrounds and disciplines, 11 food products particularly important for RTB-based staple diets in SSA were selected for the research reported in this issue. Multidisciplinary teams of breeders, social scientists, food technologists and others used new methods for capturing user quality preferences (Forsythe *et al.*, 2021; Teeken *et al.*, 2021), through surveys and product evaluations conducted with farmers, traders, processors and consumers. It is notable that the Forsythe *et al.*'s paper (described further below) is the first registered report to be published by IJFST.

The original research papers bring together new knowledge about quality traits required for RTB varieties to successfully meet diverse user preferences and expectations, at each step along the variety development and RTB value chains (production, processing, marketing, food preparation, consumption). Papers address key problems in the breeding of RTB crops in SSA: inadequate understanding of requirements for different end uses, missing information on the physicochemical factors determining these requirements and absence of high-throughput screening protocols. The review papers provide a broad overview of RTB

doi:10.1111/ijfs.14911

Table 1 RTB food supply ranking in principal producing countries of Africa (2017) (kg per capita per year)

RTB Rank	Countries	Cassava (Kg/capita/yr)	Yams (Kg/capita/yr)	Potato (Kg/Capita/Yr)	Sweetpotato (Kg/Capita/Yr)	Other Roots (aroids) (Kg/Capita/Yr)	Total Starchy Roots (Kg/Capita/Yr)	Bananas (All types) (Kg/Capita/Yr)	Total RTB (Kg/Capita/Yr)
1	Ghana	232	155	0	4	28	419	125	544
2	Rwanda	104	4	93	84	12	297	209	505
3	Côte d'Ivoire	101	194	0	0	0	295	51	346
4	Malawi	90	0	52	134	0	277	44	320
5	Congo	269	3	2	1	10	285	31	315
6	Central African Republic	153	87	0	0	26	266	29	295
7	Benin	117	161	0	5	0	284	1	285
8	Gabon	76	64	1	2	20	163	110	273
9	Nigeria	119	101	5	14	8	246	15	261
10	Uganda	78	0	4	51	0	133	120	254
11	Sao Tome and Principe	6	10	2	0	28	46	196	243
12	Angola	158	0	15	34	0	207	35	242
13	Mozambique	193	0	9	23	0	225	16	241
14	Cameroon	99	13	6	13	24	156	77	233
15	United Republic of Tanzania	71	0	20	72	0	163	53	215
16	Togo	105	71	0	1	2	179	3	181
17	Guinea	97	9	5	15	7	133	49	181
18	Liberia	102	4	0	5	5	116	37	153
19	Namibia	0	0	19	0	127	146	2	148
20	Sierra Leone	107	0	0	23	0	130	6	136
21	Madagascar	92	0	5	20	5	122	13	135
Colour correspondence (Kg/capita/year):		200-300	150-200	100-150	50-100	0-50			

Faostat, new food balance. http://www.fao.org/faostat/en/#data/FBS

production and use trends (Scott, 2021), describe case studies of varietal change (replacing old varieties with new ones) (Thiele *et al.*, 2021), summarise analytical methods for rapid quality assessment of yam and cassava using near-infrared spectroscopy (Alamu *et al.*, 2021), describe gari end-user preferences (Awoyale *et al.*, 2021) and review the literature to develop a product profile for fried sweet potato in West Africa (Carey *et al.*, 2021).

Roots, tubers and bananas play an essential role as staple foods in the tropics and subtropics, and particularly in Africa where they are culturally highly valued (Muimba-Kankolongo, 2018; Kennedy *et al.*, 2019; Lebot, 2019; Petsakos *et al.*, 2019; Scott, 2021). Key RTB crops in the African context are cassava, cooking bananas/plantains, yams, sweet potatoes and potatoes (FAO, 1990; Lebot, 2019). Due to their adaptability in different ecosystems and high yields compared with local cereals, they are a primary and reliable source of calories for populations in SSA. However, these crops are highly perishable and difficult to store or transport due to their bulkiness and high moisture content. In order to overcome these issues, and in the case of cassava, to reduce levels of the toxic cyanogenic compounds, a wide range of processes have been developed over millennia to convert fresh roots and tubers into a wide array of more stable and safe products with preferred local traits (Hahn, 1989).

Table 1, based on FAO's *new food balance* data FAOSTAT, (2018), shows the overwhelming dietary importance of cassava, yam and cooking bananas in SSA, with total RTB consumption well above 100 kg per capita per year in most countries. By way of comparison, RTB consumption in Europe and North America is around 60 kg per capita per year, mainly potatoes.

Faostat, new food balance. http://www.fao.org/faostat/en/#data/FBS

The ranking of countries (first column) corresponds to the importance of total RTBs in local diets, as shown in the last column. FAO estimates that 342 million tonnes of RTBs were produced in Africa in 2018, 34% of which in Nigeria alone and 52% in West Africa (FAOSTAT, 2018). Cassava contribute 50%; yam, 21%; sweet potato, 8%; potato, 8%; cooking bananas, 6%; and dessert bananas, 4% of the African RTB production (FAOSTAT, 2018; Lescot, 2020). This major RTB consumption is distributed across the SSA tropical belt (Fig. 1).

Cassava, yam and plantain contribute to the development of original African cuisines without mimicking exogenous cuisine or the westernisation of African urban consumption. Bricas *et al.* (2016) showed the capacity of African urban markets to drive the development of RTB local food chains in relation to the preferences and needs of users. A research priority is to adapt RTB value chains to this urbanising context so that consumers can have ready access to these foods and more nutritious options (Petsakos *et al.*, 2019; Thiele & Friedmann, 2020).

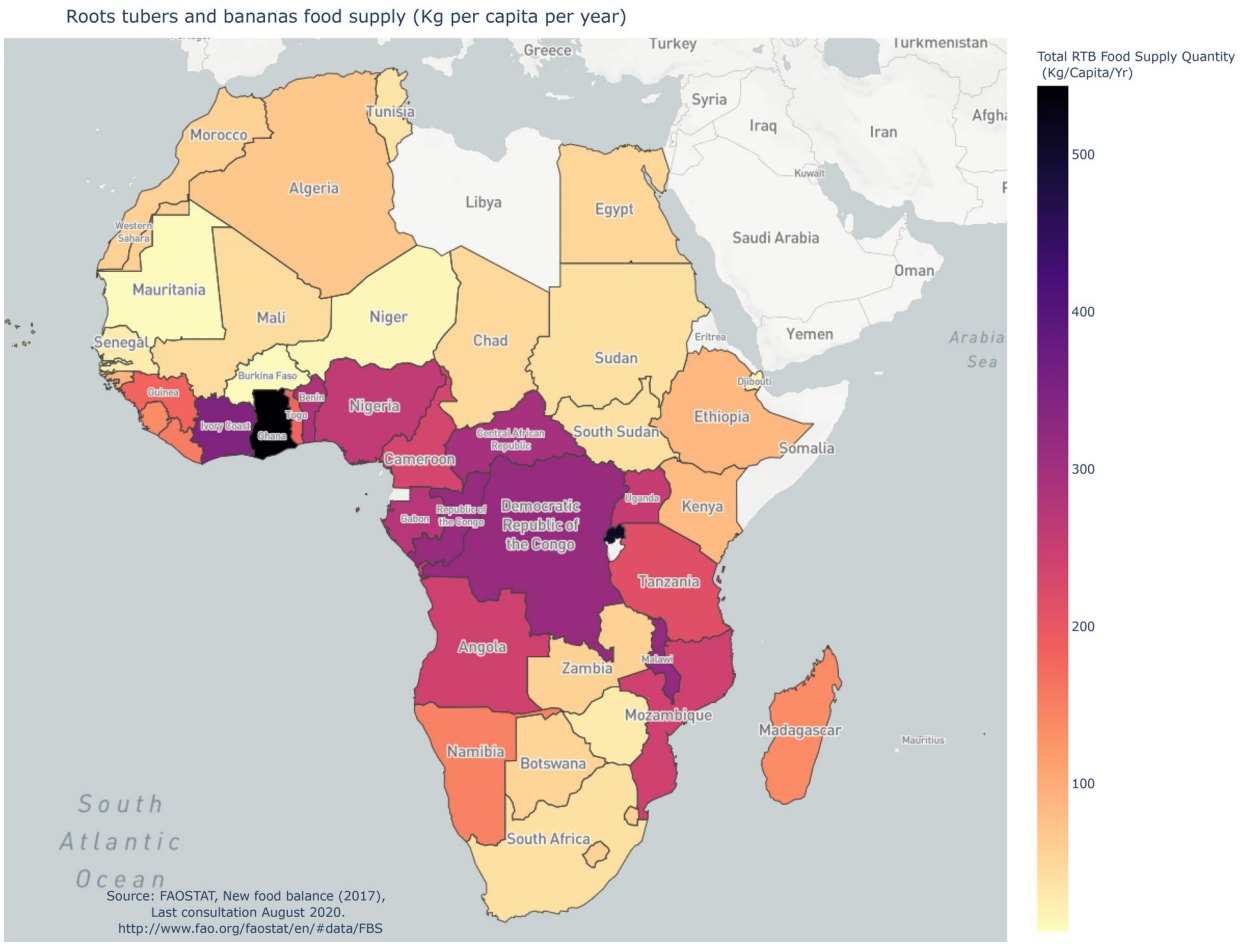

Figure 1 Map of RTB food supply in Africa, 2017 (kg per capita per year).

In Africa, women play crucial roles in the production, processing and preparation of RTB crops, but their input is often under-valued in technology design that may affect any of these activities (Rubin & Manfre, 2014; Weltzien *et al.*, 2020). Many of the studies in this special issue looked specifically at the current and potential women's benefits through their participation in optimised product quality evaluation and critical feedback to breeding programmes.

RTBs are mainly consumed directly in SSA as boiled pieces or pounded in the form of smooth, not sticky, and stretchable dough. They are also stewed, steamed or fried and eaten with African traditional soups. Cassava is generally boiled, stewed or steamed in eastern and southern Africa, and in West Africa is usually processed directly after harvest into derivative products, for example whole root fermentation and softening through retting (fufu, lafun, bâton, chikwangue); heap fermentation (kwon); and fermentation/dewatering of the mash after grinding, followed by steam cooking (attiéké), roasting (gari) and dough formation (eba). All these unit operations are part of the formulation of food products with quality traits strongly sought after by local consumers. Hahn (1989) showed the importance of these different processing techniques in relation to the geographical distribution of key cassava products in SSA. Farmer processors and consumers have strong preferences in terms of raw material quality, depending on the processes developed for the formulation of each cassava-based food (Béchoff *et al.*, 2018).

Breeding programmes for RTB crops initially gave priority to yield, dry matter and disease/pest resistance. As progress in these basic requirements has been met, they must now focus on end-product quality traits and processor and consumer preferences for quality characteristics. Processing ability and quality of end products are a common issue across improved varieties of RTBs, and this can contribute to low levels of varietal adoption and its subsequent benefits (Thiele *et al.*, 2021).

To address these challenges, an interdisciplinary five-step methodology was developed for the RTBfoods project to better understand consumer preferences for quality characteristics among diverse user groups along the food chain (Forsythe *et al.*, 2021). The methodology includes a state of knowledge review, consultations with key informants and rural communities, diagnostics of process performance (technical and socio-economic) with experienced processors, and consumer testing in urban and rural areas. Quality characteristics are then prioritised into a food product profile. Through testing and analysis, individual quality characteristics are associated with biochemical and physical traits of RTB fresh materials, which can be shared with breeders to develop improved selection tools. Many of the papers in the special issue report result from the application of this methodology. Physicochemical scientists, food technologists and breeders then need to jointly develop and implement high-throughput phenotyping systems to screen large numbers of potentially improved genotypes and achieve significant genetic gains towards acceptable varieties for both producers and end users.

According to research reported in this special issue, the main characteristics preferred by RTB consumers of boiled products are rapid softening and/or the development of friability or mealiness during cooking. For pounded products, the main objective is to obtain a smooth and stretchy dough with easy-to-swallow texture, colours and taste/aroma typical of each RTB (matooke, pounded yam, eba). For cassava-derived products, colour, acidity due to fermentation, stickiness in the fingers and texture of the dough in the mouth are key sensory traits. Additionally, the swelling characteristics of gari (in cold or hot water), attiéké (during steaming) and fufu (in hot water) contribute to consumer preferences.

In summary, this special issue defines and communicates an improved knowledge of the end-user preferred quality characteristics of RTB products. This knowledge helps elaborate goals for both the processing unit operations (food scientist control) and variety traits (breeder control). A dynamic and close interaction among social scientists, food technologists, biochemists and plant breeders will contribute to better end-user acceptance and the successful deployment of technologies, for a positive impact on RTB value chains in Africa.

Author Contributions

Dominique Dufour: Conceptualization (lead); Funding acquisition (lead); Investigation (supporting); Methodology (supporting); Project administration (lead); Supervision (lead); Validation (equal); Writing-original draft (lead). **Clair H Hershey:** Conceptualization (supporting); Writing-original draft (supporting); Writing-review & editing (lead). **Bruce Rankin Hamaker:** Conceptualization (equal); Writing-review & editing (equal). **Jim Lorenzen:** Conceptualization (equal); Funding acquisition (lead); Project administration (supporting); Resources (lead); Supervision (supporting); Validation (supporting).

References

Alamu, E.O., Nuwamanya, E., Cornet, D. *et al.* (2021). Near-infrared spectroscopy applications for high-throughput phenotyping for cassava and yam: a review. *International Journal of Food Science and Technology*, Special Issue: Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding **56**(S1), (same issue). https://doi.org/10.1111/ijfs.14773–.

Awoyale, W., Alamu, E.O., Chijioke, U. *et al.* (2021). A review of cassava semolina (Gari) end-user preferences and implications for varietal trait evaluation. *International Journal of Food Science and Technology*. Special Issue: Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding, **56**(S1), https://doi.org/10.1111/ijfs.14867

Béchoff, A., Tomlins, K.I., Fliedel, G. *et al.* (2018). Cassava traits and end-user preference: relating traits to consumer liking, sensory perception, and genetics. *Critical Reviews in Food Science and Nutrition*, **58**, 547–567.

Bricas, N., Tchamda, C. & Martin, P. (2016). Are the cities of West and Central Africa so dependant on food imports? *Cahiers Agricultures*, **25**, 10.

Carey, T., Ssali, R. & Low, J. (2021). Literature review to guide development of a product profile for fried sweetpotato in West Africa. *International Journal of Food Science and Technology*; Special Issue: Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding, **56**(S1), (same issue). In press.

FAO (1990). *Roots Tubers Plantains and Bananas in Human Nutrition*. p. 182. Food and nutrition series. Rome: Food and Agriculture Organization of the United Nations. FAO food and nutrition series, no 24. ISBN 92-5102862-1.

FAOSTAT (2018). *FAO New food balance 2017*, last consultation November 2020. http://www.fao.org/faostat/en/#data/QC

Forsythe, L., Tufan, H., Bouniol, A., Kleih, U. & Fliedel, G. (2021). An interdisciplinary and participatory methodology to improve user acceptability of root, tuber and banana varieties. *International Journal of Food Science and Technology*; Special Issue: Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding, **56**(S1), (same issue). https://doi.org/10.1111/ijfs.14680

Hahn, S.K. (1989). An overview of African traditional cassava processing and utilization. *Outlook on Agriculture*, **18**, 110–118.

Kennedy, G., Raneri, J.E., Stoian, D. *et al.* (2019). Roots, tubers and bananas: contributions to food security. *Encyclopedia of Food Security and Sustainability*, **3**, 231–255.

Lebot, V. (2019). *Tropical Root and Tuber Crops: Cassava, Sweet Potato, Yams and Aroids* (Crop Production Science in Horticulture). 2nd edn, p. 544. Wallingford: CABI.

Lescot, T. (2020). Banana genetic diversity. *Fruitrop*, **269**, 98–102.

Muimba-Kankolongo, A. (2018). Root and Tuber Crops. In: *Food Crop Production by Smallholder Farmers in Southern Africa: Challenges and Opportunities for Improvement*. Chapter 9, Pp. 123–172. Amsterdam: Elsevier.

Petsakos, A., Prager, S.D., Gonzalez, C.E. *et al.* (2019). Understanding the consequences of changes in the production frontiers for roots, tubers and bananas. *Global Food Security*, **20**, 180–188.

Rubin, D. & Manfre, C. (2014). Promoting gender-equitable agricultural value chains: issues, opportunities, and next steps. In: *Gender in Agriculture* (edited by A. Quisumbing, R. Meinzen-Dick, T.

Raney, A. Kroppenstedt, J. Behrman & A. Peterman). Pp. 287–314 Dordrecht: Springer.

Scott, G. (2021). A review of root, tuber and banana crops in developing countries: past, present, and future. *International Journal of Food Science and Technology*; Special Issue: Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding, **56**(S1), https://doi.org/10.1111/ijfs.14778

Teeken, B., Agbona, A., Abolore, B. *et al*. (2021). Understanding cassava varietal preferences through pairwise ranking of gari-eba and fufu prepared by local farmer-processors. Special Issue: Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding, **56**(S1), (same issue). https://doi.org/10.1111/ijfs.14862

Thiele, G., Dufour, D., Vernier, P. *et al*. (2021). A review of varietal change in roots, tubers and bananas: consumer preferences and other drivers of adoption and implications for breeding. *International Journal of Food Science and Technology*; Special Issue: Consumers have their say: assessing preferred quality traits of roots, tubers and cooking bananas, and implications for breeding, **56**(S1), (same issue). https://doi.org/10.1111/ijfs.14684

Thiele, G. & Friedmann, M. (2020). The vital importance of RTB crops in the One CGIAR portfolio. RTB Research Brief 02. 4 p. Lima, Peru: CGIAR Research Program on Roots, Tubers and Bananas. https://cgspace.cgiar.org/handle/10568/109915, https://cgspace.cgiar.org/bitstream/handle/10568/109915/The%20vital%20importance%20of%20RTB%20crops_ResearchBrief02.pdf?sequence=3&isAllowed=y

Weltzien, E., Rattunde, F., Christinck, A. & Ashby, J. (2020). Gender and farmer preferences for varietal traits: evidence and issues for crop improvement. *Plant Breeding Reviews*, **43**, 243–278.