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Letter

Valuation of Rice Postharvest Losses in Sub-Saharan Africa and Its Mitigation Strategies

Data on rice harvest and postharvest loss in Sub-Sahara Africa (SSA) is scanty making it difficult for stakeholders to appreciate the loss and set priority areas for loss reduction along the value chain. To address this problem, a protocol was developed and validated for postharvest loss (PHL) quantification in SSA. Quantitative losses at each segment were determined by field measurements. Interactive effect of origin of rice (domestic versus imported) and type of processing (white versus parboiled milled) on rice price in 33 markets in Africa was used to estimate qualitative loss for both white and parboiled milled rice. Total PHL for rice in SSA in 2018 is estimated at about US$ 10.24 billion, representing 47.63% of the expected total production. The highest loss recorded was quantitative loss before and during harvesting, followed by qualitative loss along the entire value chain, quantitative loss during milling, parboiling, threshing in that order, with the lowest being quantitative loss during drying. Priority areas to be targeted for PHL reduction in SSA and some loss mitigation tools and technologies piloted or suitable for SSA are proposed.

Paddy rice production in SSA in 2018 was estimated at 26.5 million tons from a total of 11.95 million hectare of harvested area (IRRI, 2020), but this quantity did not reach the table of consumers due to PHL that can be subdivided into quantitative (weight) and qualitative (value) loss. Quantitative PHL in grains is estimated at 17%, but significant differences exist between directly measured losses and estimates obtained by interviews (Prusky, 2011; Minten et al, 2020), demonstrating the poor knowledge of actual losses by value chain actors. Grolleaud (1997) estimated rice quantitative PHL during harvesting and threshing processes at 5%–16%, while during drying, storing, milling and processing at 5%–25%. Yong (1997) estimated rice losses in China at 5%–23% (excluding processing) while in Vietnam at 10%–25% under typical conditions and 40%–80% under extreme conditions of inadequacy in storage facilities, high temperature and humidity (Stuart, 2011). Most of the PHL estimation research has focused on quantitative loss with complete neglect of qualitative loss which makes the reported estimates incomplete (Prusky, 2011). In addition, PHL estimation on rice has mostly been done in Asia although rice is also an important staple crop widely cultivated in Africa. Efforts to identify and resolve postharvest issues along the rice value chain in many SSA countries are impeded by the lack of a simple, adoptable and well-defined practical methodology for estimating PHL.

Rice yield gap in Africa is estimated at 5.8 t/hm^2 (Africa Development Bank, 2016), and the causes of this difference between the actual farm yield and yield under best practice have been well documented (Tanaka et al, 2015). There is, however, a need to reduce current knowledge deficits and improve our understanding of postharvest practices and losses in SSA. This will require an understanding of the point of losses, their magnitude and factors affecting those losses. Many years of high dependency on rice imports by SSA, with imports now expected to reach 12.6 million tons or USD 5.5 billion annually by 2025 (Africa Rice Center, 2018), have made imported rice the benchmark upon which consumers in the region valuate the quality of different rice types on the market (Futakuchi et al, 2013). It is thus possible to use an interactive model of processing type (white versus parboiled milled) and origin (domestic versus imported) on price to determine the qualitative loss with imported rice as reference. This will enable both intrinsic and extrinsic factors that cause upgrading or downgrading of rice at the point of sale to be captured.

The metrics used in reporting PHL are not well defined as many authors report cumulative percentage weight loss as total PHL while excluding qualitative (value) loss. This has made it impossible to have credible data on rice PHL especially from SSA. To resolve this issue, Africa Rice Center (AfricaRice) and its partner (National Agricultural Research Institutes, NARIS), operating within the context of the Africa-wide Postharvest and Value-Addition Task (APVATF), set as one of their objective to the develop and validate an integrated approach to assess quantitative and qualitative losses from harvest to milling. This is critical because PHL in developing countries occurs during production, harvest, post-harvest and processing phases

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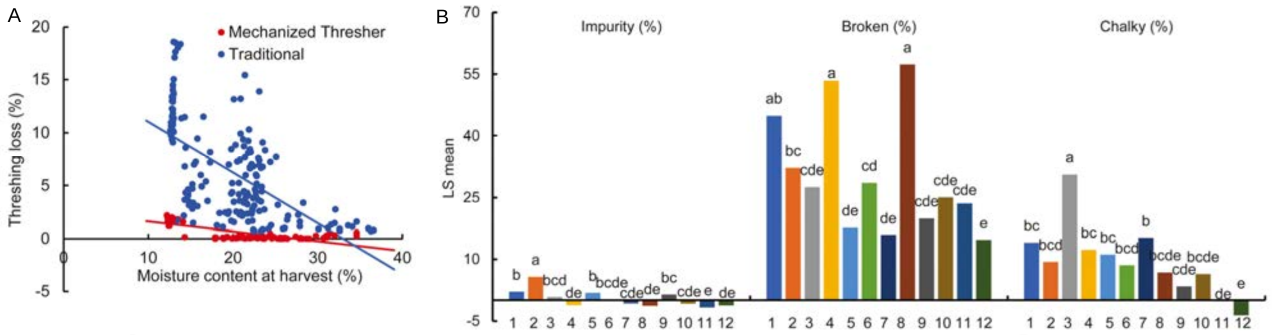
contrary to retail and consumer levels in developed countries (Prusky, 2011). The methodology consisted of establishing an experimental protocol that included measurement of both quantitative loss parameters during harvesting, threshing, drying, parboiling and milling and qualitative parameters (impurity/cleanliness, and head-rice/broken-rice ratio) during harvesting, threshing and drying. In addition, the appearance of rice (impurity/cleanliness, head-rice/broken-rice ratio and chalkiness) was evaluated in several rice sector development hub across Africa (Africa Rice Center, 2018). Furthermore, the effects of the proportion of impurities, head rice and chalky grains on the price of rice at milling sites were also evaluated. Finally, the interactive effect of rice origin and processing type on price was used to valuate qualitative loss. It is important to note the heterogeneity in varieties cultivated within study sites and between sites. However, only the most popular variety at each site was evaluated. The protocol was validated by the Africa-wide Postharvest and Value-Addition Task focal point in each country who are employees for the NARIS. It should be noted that not all countries were able to look at every segment of their rice value chain, in part because some countries do not have every segment (e.g. there was no parboiling in Uganda at the time of this study) and in part because some national partners have no enough resources to cover all segments in the time available. As such, detailed results are best considered on a ‘losses per value-chain segment’ basis. These allowed for the generation of mean losses per segment that are used to estimate total PHL for SSA. Two scenarios were considered for the measurements: farmers’ ‘traditional’ conditions and practices (Scenario 1), and ‘ideal’ conditions in the form of the best currently available postharvest practices and technologies (Scenario 2). Imported rice was considered as a reference for rice quality trait evaluation. The detailed materials and methods used for the estimation of rice PHL in SSA are shown in File S1.

Average yield recorded from the study sites at optimum harvesting time (OHT) and farmer’s harvesting time (FHT) was 5.3 and 4.1 t/hm^2, respectively (Table S1). Average shattering (grain collected on ground in harvested plots) and stacking (grain collected on the ground where harvested and panicles were gathered prior to threshing) losses were 2.8% and 4.2%, respectively. Manual threshing resulted both in high grain loss due to un-threshed grains that remained on the panicle after threshing (1.9%) and scattered grains during threshing (1.6%). As the paddy moisture content increased from 15% to 30%, harvesting loss at farmer’s fields decreased both for traditional and improved harvesting ($F = 116$, $P < 0.0001$, $R^2 = 0.58$) (Fig. 1-A). Grains abandoned on the drying surface were highest in Nasarawa, Nigeria (0.79%) and lowest in Gagnoa, Côte d’Ivoire



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Parameter	Expected total production (t)	Loss factor	Effective paddy (t)	Effective milled rice (t)	Value (US$)	PHL (%)
Harvesting	34 130 000	0.226	7 713 380	4 951 989.96	4 857 902 151	22.6
Threshing	34 130 000	0.027	921 510	591 609.42	580 368 841	2.7
Drying	34 130 000	0.004	136 520	87 645.84	85 980 569	0.4
Parboiling	34 130 000	0.029	989 770	692 84	679 675 059	3.2
Milling	34 130 000	0.080	2 730 400	1 752 916.80	1 719 611 381	8.0
Quantitative loss Scenario 1 (SI)	34 130 000	0.366	12 491 580	8 077 001.02	7 923 538 001	36.9
Quantitative loss Scenario 2 (S2)	34 130 000	0.029	1 000 009	642 005.78	629 807 668	2.9
Quantitative loss (S1-S2)		0.337	11 491 571	7 434 995.24	7 293 730 332	33.9
Available paddy after loss subtraction	21 638 420	0	21 638 420	13 891 865.64	13 627 920 193	
Qualitative loss in available rice					2 943 630 762	21.6
Total PHL for rice in SSA					10 237 361 094	47.6
Expected production	34 130 000	0	34 130 000	21 911 460.00	21 495 142 260	

Milling return is 0.642. Mean price of imported rice is 981 US$/t. PHL, Postharvest loss.

Fig. 1. Grain losses during different stages in countries of Sub-Saharan Africa (SSA).

A, Regression of threshing loss by grain moisture content of paddy threshed by farmers ($R^2 = 0.579$). Traditional is manual threshing by beating panicle on a log of wood and mechanical threshing using motorized thresher such as the ASI-thresher.

B, Proportion of impurities, broken rice and chalky grains in rice from different sites across Africa. Different lowercase letters within each quality attribute (impurity, broken and chalky grain) indicate significant difference at the 0.05 level. Numbers 1 to 12 indicate Mali/Sikasso, Senegal/Dagana, Nigeria/Kano, Niger/Tillaberi, Benin/Glazoue, Uganda/Northern, Cameroon/Ndop, Cote d’Ivoire/Gagnoa, Ghana/Narvrongo, Gambia/West Coast Region, Tanzania/Kahama/Kilombero and Sierra Leone/Manbolo, respectively.

C, Quantitative and qualitative rice postharvest loss from harvesting to milling in Sub-Sahara Africa in 2018.

(0.01%). Traditional parboiling recorded a higher amount of grains abandoned during washing (1.54%), soaking (1.32%) and steaming (1.10%) compared to the improved method [Grain quality enhancer, Energy-efficient and durable Material (GEM) parboiling] (Ndindeng et al, 2015a). Grain loss was higher for traditional mills (11.26%) compared to improved mills (2.34%) with the highest amount of grain loss being those that dropped during milling (4.94%) (Table S1).

The proportion of impurities was not influenced by harvesting time nor by variety but by threshing and drying methods. Farmer's threshing and drying methods increased the proportion of impurities in the rice compared to rice threshed or dried using improved methods (Table S2). Head rice was influenced by variety, harvesting time, threshing method and drying methods. Farmer's practices during harvesting, threshing and drying reduced head rice by 8.5%, 5.0% and 13.3%, respectively, compared to improved methods while NERICA-L-19 recorded higher head rice yield than TOX3145. The proportion of impurities, broken and chalky grains showed large variations between sites and within sites. Impurities were generally below 5% except for Senegal/Dagana (LS mean = 5.7%). The proportion of broken rice was > 14% in all the 12 study sites with highest values recorded in Côte d'Ivoire/Gagnoa (LS mean = 57.3%) and Niger/Tilaberi (LS mean = 53.4%) (Fig. 1-B). The mean proportion of chalky grain was < 20% except for Nigeria/Kano (LS mean = 30.6%).

The price of rice at milling sites was influenced by the proportion of broken rice, chalky grains and site ($F = 29.6$, $P < 0.0001$, $R^2 = 0.68$). As expected, broken and chalky grains recorded discount prices (Table S3). The interactive effect of rice origin and processing on price showed that imported white rice recorded the highest mean price (1.077 US$/kg), followed by imported parboiled (0.986 US$/kg), domestic white (0.844 US$/kg), while domestic parboiled recorded the lowest (0.817 US$/kg). The percent losses in value of domestic white rice and domestic parboiled rice with respect to imported counterparts were estimated to be 21.6% and 17.1%, respectively.

The mean percent grain loss after the crop is ready for harvest and during harvesting is estimated at 22.64%, and out of this only 7% is accounted for shattering loss and stacking loss (Table S1). The rest (15.64%) was unaccounted for, and this may be due to the actions of farm pests. Equations for the determination of percent quantitative loss at each value chain segment, when only traditional or improved methods are used, were developed using mean losses at each value chain segment and the Expected Total Production (ETP) X as indicated in File S1.

Rice yield in SSA in 2018 was estimated as 2.21 t/hm^2 (IRRI, 2020). In the present study, 22.64% average loss in yield due to late harvesting was recorded. This implies that the expected yield in SSA in 2018 was 2.85 t/hm^2 and the Expected Total Production (ETP) was 3.4×10^7 t from a harvested area of 1.2×10^7 hm^2. Percent quantitative PHLs during threshing, drying, parboiling and milling are estimated as 2.7%, 0.4%, 3.2% and 8.0% respectively of this ETP (Fig. 1-C). The difference of total quantitative PHL between Scenario 2 and Scenario 1 was 33.93%. Based on the interaction between rice processing type and origin on price, the qualitative loss for white milled domestic rice was estimated as 21.6% of the value of the available rice after quantitative loss reduction which is 2.9 billion US$. Total PHL (quantitative and qualitative) for rice in SSA in 2018 was thus estimated at about 10.2 billion US$ when all the rice is straight milled, representing 47.63% of the value of the ETP. The highest loss as a percentage of total PHL was recorded when the rice was mature and remained unharvested and during harvesting (43.8%), followed by qualitative loss along the entire rice value chain (28.8%), quantitative milling loss (15.5%), quantitative parboiling loss (6.1%) and quantitative threshing loss (5.1%), with the lowest being quantitative drying loss (0.8%).

About 47.6% PHL demonstrates losses under extreme conditions of inadequate on-farm and postharvest practices, high temperature and humidity as suggested by earlier studies in Vietnam (Stuart, 2011), which is considered now as typical conditions in SSA. Based on this study, rice loss reduction priority in order of importance in SSA should thus be on reducing quantitative loss after rice is mature for harvest and during harvesting, increasing the quality of domestic rice along the value chain, and reducing quantitative loss during milling, parboiling and threshing. With 36.9% of total quantitative PHL, SSA will have to increase production by about 52% to offset the loss (Bourne, 2014) if rice consumption level of 3.3×10^7 t in 2018 (IRRI, 2020) is considered. Generally, within a given value chain segment, high variabilities in grain losses were observed within and between sites highlighting the heterogeneity in biophysical and socio-economic factors, on-farm and postharvest practices. The high variability in grain losses observed in this study is in conformity with earlier studies where grain quality traits showed large variations across and within agro-ecological zones and production systems (Mapiemfu et al, 2017). In addition, Prusky (2011) reported extreme variability in the magnitude of both quantitative and qualitative PHL. Higher proportions of broken grains for samples harvested, threshed and dried using farmer's practices may be due to the development of fissures in the grains that translates to high breakages during milling. Fissures in rice grains may be caused by moisture re-absorption by dry paddy, moisture re-absorption by field paddy grains or by rapid drying of paddy (Zhou et al, 2009). Moreover, the hitting of panicles on logs of wood or drums during manual threshing (as commonly practices in SSA) may also cause fissures in the grains. One of the strategies to improve the quality of domestic rice is parboiling, which is the hydrothermal treatment of paddy before milling to improve its physical and nutritional quality (Ndindeng et al, 2015a; Zohoun et al, 2018a, b). Previously, it was shown that improved parboiled samples recorded higher proportion of head rice (91%–95%) and lower proportion of impurities (< 0.4%), compared to rudimentary parboiled samples (Ndindeng et al, 2015a). GEM parboiled rice also recorded a premium price (0.23 US$) compared to rudimentarily parboiled rice whose benchmark value was 0.58 US$ (Akoa-Etoa et al, 2016), demonstrating GEM parboiling methods as a qualitative loss reduction technology. Engelberg type mills were shown to record lower proportion of head rice (35%–49%) compared to Satake rubber roll type series (53%–62%) and laboratory milling system (83%–90%).

The transformation of Agriculture in Africa is expected to address constraints in five key areas: (i) under performed value chains, (ii) insufficient infrastructure, (iii) limited access to agricultural finance, (iv) adverse agri-business environment, and (v) limited inclusivity, sustainability and nutrition. Some of these constraints directly or indirectly lead to high PHL recorded in SSA. In order to address these constraints and mitigate PHL, governments will have to prioritize infrastructural development (road, energy, water, drying and storage facility) in rural areas to improve production and connect farmers to downstream activities, set-up innovative financial instruments to both de-risk investments and crowd in private sector financing and create an enabling environment for agriculture and agri-businesses to thrive (African Development Bank, 2016). Research and development institutions in collaboration with other value chain actors will have to implement the following context specific PHL mitigation technologies and tools: (i) create and facilitate rice innovation platforms in rice production sites to improve linkages and value chain governance, (ii) replace current varieties with preferred varieties coupled with varietal zoning, which should be high-yielding, short duration with high-milling recoveries, slender in shape, aromatic (for most parts of Africa) and of intermediate to high amylose content, (iii) promote small-scale harvesting and threshing technologies such as rapid rice cutters coupled with mechanical threshers such as the AfricaRice-SAED-ISRA (ASI)-thresher, (iv) support the setting up of modern small-scale rice processing facilities such as the GEM parboiling facility setup in several rice sector development hubs across Africa (AfricaRice, 2019), (v) promote hermetic storage systems, and (vi) value-addition to low-grade broken rice through the production of rice flour for bakery products (Eyenga et al, 2020) and use of rice husk and straw for clean energy, organic fertilizer and building material production (Ndindeng et al, 2015b, 2019; Migo-Sumagang et al, 2020). The support research and development institution should focus on piloting of best PHL reduction practices and technologies, training of postharvest equipment fabricators, training of trainers on the use of postharvest technologies, supporting large-scale training of end-users and facilitating the access of credits for the purchase of harvesting and postharvest equipment.

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SUPPLEMENTAL DATA

The following materials are available in the online version of this article at http://www.sciencedirect.com/journal/rice-science; http://www.ricescience.org.

File S1. Methods and technological support to reduce rice loss.

Table S1. Mean percent yield and losses during harvesting, drying, parboiling and milling at different sites in Africa.

Table S2. Effects of variety, harvesting, threshing and drying method on proportion of impurities and head rice.

Table S3. Effects of grain quality on price of rice at milling sites, rice processing type and origin on postharvest loss.

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