# Climate Smart Dry Chain for Food and Nutrition Security in Nepal

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## Abstract

Global efforts to feed the burgeoning population have focused on increasing food production and access. In the meantime, FAO estimates about 1/3 food loss in the developing countries. To minimize these losses, grain storage techniques were investigated in an earthquake hit village in Kavre district of Nepal. Pesticide free moisture proof/airtight food storage bags were provided to 1,055 households using financial support from UNICEF-Nepal. Thirty-three households were identified who could store food grains for 6-month for this study. Maize and rice grains were stored in porous and in moisture-proof hermetic bags. Food grain samples were collected at the beginning and at 6-month and were analyzed for physical quality parameters, nutrients and mycotoxins. About 92% insect damage occurred in maize stored in porous bags which was prevented in triple layer hermetic Purdue Improved Cowpea Storage (PICS) bags. Insect damage in paddy remained low within 10% in both treatments. Major maize nutrient loss occurred through insect damage. The traditional practice was to use insect and mold infested maize as feed. Mycotoxins results showed that toxigenic molds develop in open storage

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of improperly dried grains especially maize. Fusarium-related mycotoxins associated with stunting were detected in maize samples using LC-MS/MS equipment. Mature grains should be dried sooner to processing moisture contents and packaged into moisture-proof hermetic bags (Dry Chain) to minimize postharvest loss. A clear policy implication is that use of improved low-cost Dry Chain technology should be promoted to enable quality food systems.

**Keywords:** Mycotoxins, Nutrition, Food Loss, Dry Chain, Climate Smart, Moisture-proof Hermetic Bags.

## Introduction

Despite considerable investments made and a multitude of programs introduced over the past decades, malnutrition remains a major threat to the health and well-being of children and mothers in many countries. In Nepal, over 40% of children under five suffer from stunting, 11% from wasting, and 29% are underweight (Nepal Demographic Health Survey, 2011). Malnutrition adversely affects the health of children and mothers and their immune system making them susceptible to diseases, and subsequently leads to the vicious cycle of poverty and hunger. Major causes of child malnutrition relate to poor maternal nutrition and inadequate nutrient intake due to household food insecurity and poor feeding practices. Lack of knowledge to maintain quality in storage leads to nutrient loss (Garbaba et al., 2017). Carcinogenic mycotoxins also build up following poor storage of dry foods (Wild et al., 2015). Improperly stored dry food is also damaged by insects that account for about 43% of the total physical and nutritional loss in the developing world. Insects and molds co-infest the grains, and cause nutrient losses illustrating the role of quality food in nutrition and health (Bakhtavar et al., 2019). As quality health care is gaining attention than just mere access to it, efforts to improve food quality could be a better preventive measure in public health management (Ceschia, 2018; Dahal et al., 2016). In order to improve the quality of stored food at farms, moisture content has been identified as the culprit for quality loss (Bradford et al., 2018). Although the pharmaceutical, food processing and seed industries have embraced moisture management strategies to minimize quality loss in the developed countries, the same concepts have yet to be used for unprocessed dry food products at farms in the developing countries.

UNICEF advocates for quality foods for improving the nutrition of children and mothers in the developing countries where malnutrition is a public health concern. To this end, UNICEF and European Union collaborated to implement Multisectoral Nutrition Programs (MSNP) in 28 districts in Nepal (UNICEF, 2016). However, medical researchers have reported food borne carcinogenic mycotoxin (aflatoxin) markers in blood serum of pregnant women in Sarlahi (Groopman et al., 2014) and Banke districts (Andrews-Trevino et al., 2020). Such scenario illustrates the need to improve food quality for better nutrition and health. Following the devastating 2015 Gorkha Earthquake, UNICEF-Nepal became interested in supporting technologies to reduce food loss and enable nutrient-rich foods to the children and mothers.

A field level study was conducted to address prevention of food storage loss and nutrient quality in small farm-households in Kavre district of Nepal. In a pre-survey of the candidate village, an overwhelming concern about the poor quality of maize stored in open structures was noticed (Dahal, 2017). Thus, demonstration of dry food quality management using Dry Chain became the overriding objective of this project. Information generated from this study will be helpful for individual farmers, governmental agencies and other stakeholders in minimizing food storage loss and enhance food and nutrition security in Nepal.

## Materials and Methods

This study was conducted at Ugra Chandi Nala, now part of Banepa Municipality, in Kavre district of Nepal. UNICEF and Asta-Ja Research and Development Center (Asta-Ja RDC), Kathmandu, Nepal, collaborated to improve dry food quality in the earthquake affected Kavre district during February 2017 to March 2018. Triple layer hermetic/airtight Purdue Improved Cowpea Storage (PICS) bags were procured from NAFseeds, Patan, Nepal and used in evaluating "*Climate Smart Dry Chain*" (natural drying and moisture-proof packaging) technology on food that was harvested after cessation of rainfall. These bags were distributed to 1,055 households out of which 33 households were recruited to store 50 kgs grains in PICS bags and 10 kgs in porous cloth bags. These households were approached through the Female Community Health Volunteer (FCHV), the UNICEF-supported network at the local health post in the Ministry of Health (Female Community Health Volunteer Strategy, 1988). During pre-survey, mold and insect infestations were noticed in traditional open maize storage. Therefore, electric corn shellers were provided to these households to enable quicker shelling of corn and minimize drudgery of women who perform these farm operations.

Maize and rice grains were put into two types of containers (i.e. porous and moisture-proof hermetic bags) and the 6-month study was terminated in October 2017. One kg sample each of rice and maize from both types of containers was collected in plastic bags in April and October, and analyzed at Zest Laboratory, Balkot, Bhaktapur for physical (moisture content, 100-grain weight, insect damage) and chemical parameters (nutrients as reducing sugars (Lynch et al., 1962), vitamin B1 (thiamine (High-Performance Liquid Chromatography (HPLC) technique, HPLC Agilent 1260 Infinity, Diode-Array Detector, Wavelength 244 nm) and total aflatoxins (R5202, R-BIOPHARM AG, Germany, sensitivity range 1.7 μg/kg–45 μg/kg). It is noted that enzyme linked immunosorbent assay (ELISA) was used to quantify the total aflatoxins (AFs), and high performance liquid chromatography (HPLC) for thiamine quantification in Nepal. In order to unravel the presence of additional mycotoxins, the 6-month stored food samples that tested positive in baseline sampling were also analyzed at the Centre of Excellence in Mycotoxicology and Public Health (CEMPH) in the framework of MYTOX-SOUTH® at Ghent University, Belgium. Liquid chromatography coupled to tandem mass spectrometry (LC-MS/MS) was used to simultaneously quantify several mycotoxins (detection limits: 6.75 μg/kg for AFB1, 2.39 μg/kg for AFG2, 1.93 μg/kg for AFG1 and 1.53 μg/kg for AFB2). Other mycotoxins (nivalenol, deoxynivalenol, neosolaniol, fusarenon-X, 3-acetyl-deoxynivalenol, 15-acetyl-deoxynivalenol, diacetoxyscirpenol, alternariol, HT-2 toxin, T2 toxin, zearalenone, sterigmatocystin, fumonisin B1, B2, B3, ochratoxin A, roquefortine C and enniatin B) were also identified and quantified by LC-MS/MS (Monbaliu, 2011; Majeed et al., 2018).

## Results and Discussion

### *Moisture content*

Initial moisture content (MC) of shelled maize grains was at 13.5% (± 1.80%). Moisture-proof (airtight/hermetic) packaging maintained the initial MC during storage as measured by both change in 100-grain weight (g) and moisture content % (Wile 55 measurement). Both of these parameters tended to be more variable for maize stored in porous cloth bags (Table 1). MC of paddy in baseline samples was 14.1% (± 1.54%). PICS bags maintained initial MC until 6 months when measured by both change in 100-grain weight

**Table 1** Physical parameters 100-grain weight, and moisture contents (± S.E) of maize grains during storage at household level in wards 3, 4 of Banepa Municipality (formerly Nala VDC) during early April, 2017 through early October, 2017

| Physical Parameters | Initial (N = 18) | Final (After 6 Months) | |
|---|---|---|---|
| | | Cloth Bag (N = 14) | PICS Bag (N = 14) |
| 100 – grain weight (g) | 33.8 ± 1.01 | 26.1 ± 1.0 | 32.8 ± 0.94 |
| MC % (Wile 55 measurement) | 13.45 ± 0.38 | 12.59 ± 0.5 | 13.75 ± 0.44 |

**Table 2** Physical parameters (100-grain weight and moisture content) (± S.E) of paddy during food storage at household level in wards 3, 4 in Banepa Kavre (formerly Nala VDC) during early April, 2017 through early October, 2017

| Quality Parameters | Initial (N = 15) | Final (After 6 Months) | |
|---|---|---|---|
| | | Cloth Bag (N = 12) | PICS Bag (N = 12) |
| 100 – grain weight (g) | 2.367± 0.10 | 2.46 ± 0.11 | 2.4 ±0.11 |
| MC % (Wile 55 measurement) | 14.1 ± 0.36 | 15.08 ± 0.3 | 13.62 ± 0.5 |

(g) and MC% (Wile 55 measurement). Similar to maize, both of these parameters tended to be higher in porous cloth bags than in PICS bags (Table 2). MC of the food is the most important parameter affecting quality during storage (Bradford et al., 2018). MC of foods stored in open or porous containers varies with the prevailing weather conditions. The environmental conditions at Banepa closely match weather parameters in nearby Kathmandu. For example, average temperature (T) (23 °C) and relative humidity (RH) (74%) of Kathmandu during the experimental period predicts MC of rice at 14.9% which is very close to observed 15% MC in porous bags (Bradford et al., 2016). It is noted that initial MC of both rice and maize before storage in April 2017 was closer to 14% that is suitable for processing. Initial MC was relatively stable for both rice and maize in the hermetic bags. These PICS bags have already been shown to maintain initial MC and minimize insect infestations (Abbas et al., 2018).

### *Insect damage*

Insect damage in baseline rice was closer to 5%. Insects were not visible after 6-month long storage in the hermetic bags (Figure 1, left). Although rice moths were noticed in the porous bags after 6-month storage, damaged grains were not significantly different from the hermetic bag treatment. Insect damage in maize stored for 6-months in PICS bags was similar to baseline samples ($P = 0.151$). However, there was heavy insect damage (92% ± 8.8%)

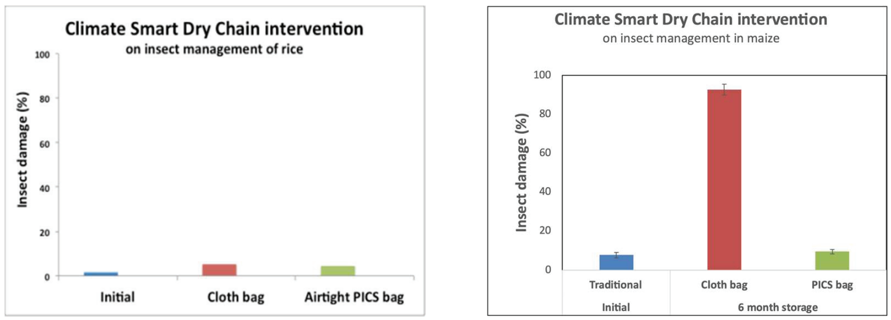


**Figure 1** The effect of pesticide-free packaging using triple layer airtight (hermetic) PICs bags on insect control of rice (left) and maize (right) during early April through early October, 2017 at Banepa Municipality in Kavre, Nepal.

in traditional porous bags that was dramatically controlled by using PICS bag (Figure 1, right; $P < 0.001$).

Airtight/moisture-proof packaging is a pesticide-free storage insect control intervention. Insects were observed getting suffocated and moving to the top region of the maize inside the hermetic bag when monitored within a week of packaging. Insect damage in corn was so serious (71–99%) that measurement of physical and chemical parameters became difficult (Table 1 and Table 2, Figure 1). FAO estimated 30% loss for low moisture foods like cereals. Other annual global losses include 40–50% for root crops, fruits and vegetables, 20% for oilseeds, meat and dairy, and 30% for fish (FAO, 2011). Most cereal losses are related to insect damage (Saujanya et al., 2013). In this study, it was observed that rice (unhusked) was more tolerant to insect damage than maize (Figure 2). However, Kumar and Kalita (2017) report variable storage losses of rice in different countries including about 15% in Nepal. Pesticide-free storage insect control is preferred method of storage insect management. Non-toxic desiccants were used to control mungbean bruchids by lowering equilibrium relative humidity (eRH) of enclosed product (Kunusoth et al., 2012). Bradford et al. (2018) suggest to lower eRH to 35% to control storage insects that corresponds to 8.8%, 9.04%, and 8.38% MC at 25°C for maize, rice and wheat respectively (Supplemental material in Bradford et al., 2016). Additional drying resources would be needed to achieve these low commodity MCs. In this study, the processing MC (about 14%) at ambient temperature (average 23°C) prevented further proliferation of storage insects of rice and corn in the triple layer PICS bags. However, lower MC would be more beneficial to minimize the loss seed quality and of nutrients during prolonged dry food storage.

### *Nutrients and sugars*

Maize reducing sugars tended to be higher in the porous and intervention group (PICS bag) as compared to the baseline maize samples. However, vitamin B1 (thiamine) in maize did not show any trend after 6-month storage (Table 3). These results could have been skewed due to using non-damaged grains for the assays. Reducing sugars in paddy seemed not to have changed as compared to baseline samples. However, vitamin B1 (thiamine) in paddy significantly declined during the 6-month storage in cloth bags ($P = 0.0034$) and but not in PICS bags ($P = 0.05$) (Table 4). Thiamine contents were also different in cloth and PICS bags at 6 months ($P = 0.047$). This trend of thiamine is similar with earlier reports. For example, vitamin B1 contents decreased by 16.7%, 17.2% and 21.4%, respectively in wheat, maize and rice at 25°C, and other nutrients like amino acid lysine decreased by 6.5% in wheat, 14.3% in maize and 23.7% in rice at 25°C during 6-month long storage (Rehman, 2006). Inability to arrest the decline of vitamin B1 in rice stored in hermetic bags could suggest a phenomenon comparable to seed germination when the decline cannot be arrested after initiation of the loss. Vitamin B1 observed in baseline maize samples was within the range observed for maize cultivars. As there are varietal differences in thiamine contents, a single variety should be used to evaluate nutrient changes (Dunn et al., 2014). About 20% decline in maize protein was observed under natural storage conditions

**Table 3** Nutrients (Reducing sugars, Vitamin B1(thiamine)) (± S.E.) of maize during storage at household level in Banepa, Kavre during early April 2017 through early October 2017

| | | Final (After 6 Months) | |
|---|---|---|---|
| Nutrients | Initial (N = 18) | Cloth Bag (N = 15) | PICS Bag (N = 15) |
| Reducing sugar as maltose equivalent (%w/w) | 0.45 ± 0.03 | 0.57 ± 0.03 | 0.53 ± 0.03 |
| Vit B1 (mg/kg) | 1.77 ± 0.17 | 1.77 ± 0.17 | 1.97± 0.14 |

**Table 4** Nutrients (Reducing sugars, Vit B1(thiamine)) (± S.E.) of paddy during storage at household level in Banepa, Kavre during early April 2017 through early October 2017

| | | Final (After 6 Months) | |
|---|---|---|---|
| Nutrients | Initial (N = 15) | Cloth Bag (N = 12) | PICS Bag (N = 12) |
| Reducing sugar as maltose equivalent (%w/w) | 0.39 ± 0.08 | 0.25 ± 0.03 | 0.35 ± 0.04 |
| Vit B1 (mg/kg) | 2.19± 0.24 | 1.21 ± 0.11 | 1.55± 0.16 |

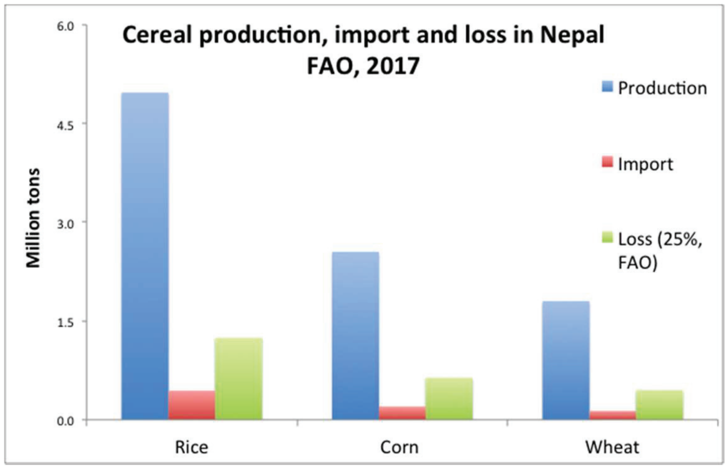


**Figure 2** National perspective of minimizing post-harvest losses that are mainly due to insects. Using FAO's data of 25% global loss (Gustavsson, 2011), storage loss for Nepal is 3 times more than import.

(Garbaba et al., 2017). Drying sooner after harvest and maintenance of lower MCs thereafter could have arrested these nutrient losses.

Reducing sugars are indicators of food quality in high moisture foods like juices, wines and sugarcane. In low moisture products like seeds, a negative correlation has been reported between reducing sugars and quality parameters as well (Cao et al., 2008). Rice reducing sugars were similar to baseline samples in both porous and hermetic bags at six months. It is noted that rice was stored by the traditional methods before the baseline samples were collected and the decline in sugars could have already flattened at the bottom. Reducing sugars in wheat grains peaked between 3–5 weeks at 20% MC and 30°C and returned to basal level (Lynch et al., 1962). However, no significant changes in the nutritional quality were observed during storage of cereal grains at temperatures less than 20°C and MCs up to 14% (Rehman, 2006). Clearly, the latter set of experiments were performed in a controlled laboratory set up, but temperature could not be regulated for storing foods at farms in low income settings. It is noteworthy that about 92% insect damage occurred in maize stored for 6 months in the porous bags but this loss was prevented in maize stored in the PICS bags. Thus, there was dramatic saving of nutrients through insect control in PICs bags. Clearly, efforts should rather be made to regulate MC soon after harvest, and carry out nutrient change studies. However, such drying studies at harvest time could not be continued due to resource limitation. Additionally, good quality food samples procured from dealers could have been used for better baseline results. Rather, we used available grains at household level to demonstrate the utility of pesticide-free Dry Chain to control storage insects transparent to the producers. Drying to 15% MC after harvest and maintenance of MC from 11%–12% had a profound impact on maize nutrients stored for upto 5 years in China (Yin et al., 2017). Drying to processing or milling MCs before hermetic packaging would be needed to minimize triple threats of nutrient loss, insects and molds infestations.

### *Molds (mycotoxins)*

Total aflatoxins (AFs) were detected in baseline samples of both maize and paddy at Zest Laboratory in Nepal. About 13% of rice samples had total AFs higher than 20 μg/kg and 86% samples contained AFs less than 20 μg/kg. Similarly, 27% of maize samples had AFs between 20–30 μg/kg. The rest of the maize samples had AFs lower than 20 μg/kg (data not shown). There was no change in AFs after storage for 6 months per ELISA assay in both treatments suggesting that the toxigenic molds were probably derived from the field before we collected the samples. Endline samples were tested for additional mycotoxins like nivalenol, deoxynivalenol, neosolaniol, fusarenon-X, 3-acetyl-deoxynivalenol, 15-acetyl-deoxynivalenol, diacetoxyscirpenol, alternariol, HT-2 toxin, T2 toxin, zearalenone, sterigmatocystin, fumonisin B1, B2, B3; ochratoxin A, roquefortine C and enniatin B, and for confirmation of AFs using LC-MS/MS at CEMPH, MYTOX_SOUTH, Ghent University, Belgium. However, AFs (B1, B2, G1, G2) were not confirmed. Only nivalenol, deoxynivalenol, neosolaniol, fusarenon-X,15-acetyl-deoxynivalenol, zearalenone, alternariol methylether, fumonisin B1, B2, B3, roquefortine C could be confirmed. In this study, Fusarium-related fumonisin B1 (1298–13658 μg/kg), fumonisin B2 (227–1936 μg/kg) and fumonisin B3 (140–1500 μg/kg) were detected in maize samples. Four out of 10 maize grain samples exceeded the CODEX limits for fumonisins that are 4000 and 2000 μg/kg respectively for grains and flours/meals. Similarly, other *Fusarium*-related mycotoxins nivalenol (776–6414 μg/kg), deoxynivalenol (61–1413 μg/kg), fusarenon-X (81–191 μg/kg), and zearalenone (484–8236 μg/kg) were detected.

It has been long known that *Aspergillu*s and *Penicillium spp.* mostly proliferate in the storage under high humidity and temperature conditions and damage the stored products. Prevalence of AFs in Nepalese maize systems has been reported (Pokhrel, 2016). As the farmers use the poor-quality products as feeds (Dahal, 2017), the mycotoxins could be transferred to meat and dairy products (Giovati et al., 2015). AF was detected in blood serum of children in nearby Bhaktapur district but the prevalence was not associated with stunting (Mitchel et al., 2017). However, increasing evidence is emerging on the association of *Fusarium*-related mycotoxins with stunting of children (Chen et al., 2018). Fumonisins were detected in cereals previously in Nepal (Desjardins et al., 2000) and in Argentina (Nogueira et al., 2018). Fumonisins caused decrease in cell viability, and increase in membrane leakage, cell death in human gastric epithelial cell line (GES-1) in vitro studies. Furthermore, toxicity potency effects were FB1>FB2>FB3 (Yu et al., 2020). Combined, these results open new avenues to address malnutrition in Nepalese children by minimizing fumonisins and other mycotoxins. Further studies should focus to assay multiple mycotoxins using sensitive LC-MS/MS equipment soon after the crop harvest to enable safer food supplies.

### *Food security*

Food and nutrition security of the growing population is a major problem in Nepal. Nepal has been increasingly importing cereals and other food items from foreign countries in recent years. Food storage loss for cereals in Nepal is three times more than imports (Figure 2, FAO, 2017), suggesting that import substitution is possible by simply minimizing food losses. In simple terms, saving the food loss is equivalent to increasing the production. While appropriate policy measures for increasing food production are necessary, immediate attention should be given to minimize post-harvest losses and enable quality food systems.

Climate smart food drying and storage technologies such as “Dry Chain” could protect food losses to annual floods as well (Poudel et al., 2017; UNICEF, 2017) and help to improve nutrition and immunity (Dahal, et al., 2020). Traditional food storage practices, which have high food storage loss and poor nutritional quality should use “Dry Chain” technology to improve food security and nutritional quality in Nepal.

## Conclusions

A simple drying technology could be very useful to protect from insects and minimize the loss of the food quality. Molds and insects are visible if the infection is severe. However, a distinct new outlook is needed to address the nutrient change during food storage. Nutrient decline will continue even if molds and insects are controlled without managing the MC of the dry foods. Furthermore, efforts to minimize loss of nutrients will need to be initiated sooner after harvest when the nutrient contents are at the peak level. Implementing "*Dry Chain*" for the short rainy season harvests involves both rapid artificial drying and moisture-proof/airtight storage. On the other hand, the "*Climate Smart Dry Chain*" would manage food quality of about 70-80% dry products harvested between rainy seasons. In combination with improved inputs and toxin reducing approaches in high moisture foods, Dry Chain could improve food quality by minimizing triple issues of toxins, insect infestations and nutrient loss. Annual government and donor (Kathmandu Post, 2015) programs should integrate interdisciplinary "*Dry Chain*" in MSNP II. Improving household nutrition through food fortification as proposed in MSNP II should also include toxin and nutrient loss minimization strategies at the earliest and dissemination through education, health, food, and trade sectors. The use of improved low-cost technology (adequate drying and hermetic packaging) to minimize loss of nutrients and food grains should be shared with the neighbors of Nepal. Furthermore, food/feed quality should be monitored using sensitive equipment to enable safe regional food supplies.

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## Biographies

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**Marthe De Boevre** is a Professor of Clinical Mycotoxicology at Ghent University, Belgium. In 2013, she graduated from the Faculty of Pharmaceutical Sciences at Ghent University with the Ph.D. dissertation 'Chemical risks related to food and feed containing masked Fusarium mycotoxins'. In 2020, she received the prestigious ERC Starting Grant for her project 'HuMyco', a multi-disciplinary project combining both fundamental and applied sciences, and contributing to disease prevention by identifying possible risks for developing cancer as a result of mycotoxin contamination. She is a section editor 'Human Health' of the World Mycotoxin Journal. Together with Prof. Dr. Sarah De Saeger, she is a coordinator of MYTOX-SOUTH, which is an intercontinental partnership to improve food security & food safety through mitigation of mycotoxins at global level. This well-structured multidisciplinary partnership, which deals with all known aspects of mycotoxins and toxigenic mould issues, is able to provide the most adequate strategies and solutions necessary for diverse stakeholders in the South.

**Sarah De Saeger** is head of the Centre of Excellence in Mycotoxicology and Public Health at Ghent University, Belgium. She is coordinator of the international thematic network MYTOX-SOUTH. As a full professor she is teaching all food-related courses in the Faculty of Pharmaceutical Sciences. The laboratory focuses on following research lines: mycotoxin detection methods, metabolomics and untargeted analysis, mycotoxins and human health, and exposomics. Research results are published in more than 360 A1 peer reviewed papers (h-index 48). She was an expert in EFSA CONTAM working groups (2011–2018) and of the Scientific Committee (SciCom) of the Belgian Federal Agency for Food Chain Safety (2015–2020). In June 2015 she established the Joint Laboratory of Mycotoxin Research of the Ghent University-Shanghai Jiao Tong University-Chinese Academy of Sciences (Shanghai Institutes of Biological Sciences). In 2015 she was awarded the Ghent University Prometheus Award for research.

**Peetambar Dahal**, Seed and Nutrition Specialist, received Ph.D. in Plant Biology (1994) and MS in Vegetable Science (1989) from University of

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