Potential of underutilized wild crops in Koraput, Odisha, India for improving nutritional security and promoting climate resilience

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Indigenous and wild crop resources play a significant role in food and nutrition security, and are also important resources for sustainable food systems under climate change. Koraput district, Odisha is one of the agro-biodiversity hotspots in India dominated by tribal communities. The plant genetic resources of this region are of significance not only for the diversity, but also their consumption pattern. The present study aimed to chronicle the nutritional value of selected neglected and underutilized crop species of Koraput. Although these plant species are useful for poor and marginalized farmers, they are largely ignored by the scientific community, breeders and policy-makers. Therefore, this study highlights the nutritional and climate-resilient traits of such species for conservation and further utilization. Mass consumption, commercialization and bio-prospecting of these valuable resources would be the right step for ensuring food and nutritional security in future climate change scenarios.

Keywords: Climate resilience, indigenous landrace, nutritional security, wild crops.

CLIMATE change impends to intensify prevailing threats to food and livelihood security and is expected to affect all components of food security such as access, availability and utilization[1]. In general, food availability has been affected by changes in arable land as well as variations in agricultural yields[2]. The transition in global food and nutrition has taken many different interventions for feeding the anticipated 9 billion population in 2050, healthily, equitably and sustainably[3]. Further, majority of the people in different countries, including India are suffering from inequality in nutrition and various micronutrient deficiencies[4]. Therefore, in many countries of the world food and nutritional security has become a major concern under climate change[5]. In spite of efforts being taken to increase the productivity of some domesticated crops, nutritional security and climate remain global concerns[6]. The number of undernourished people has increased to about 821 million globally and feeding them depends not only on improving productivity of domesticated crops but also on the use of indigenous crop species[7]. In India, around 1.38 billion people will undergo changes in their food quality as well as quantity by 2021. The transformations in the agri-food system and Westernization of diets are the key concerns of food habit in India[8]. Thus, neglected and underutilized but nutrient-rich plant species could help bring transformation in food systems and improve health and nutritional security.

Globally, climate change is expected to exacerbate various abiotic and biotic stresses[9]. The new challenge of climate change will require resilience of crop-production systems by tolerance to individual and multiple stresses[10]. Further to maintain yield stability and increase the yield, an increase in leaf photosynthesis efficiency is required in the changing climate[11]. Identification and improvement of native or traditional crops that are adaptive to local climate is one solution that can effectively resist biotic and/or abiotic stresses[12]. Several researchers advocated that locally available underutilized crop resources might possess high genetic variation and are important for climate resilience[6,13,14]. Underutilized indigenous crops are those which have originated in a specific geographic location and have undergone wide domestication leading to local varieties[14,15]. Although wild and underutilized plants have not received enough attention in food security, various researchers have recommended their use in sustainable agriculture[6,14,16]. For integrating them into developmental interventions, region-specific assessment of these neglected and underutilized species is necessary[17].

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Koraput is a tribal-dominated district of Odisha and a hotspot of agro-biodiversity in the Eastern Ghats of India[18]. In the global context, the plant genetic repository of this region assumes greater significance and Koraput is considered as a centre of diversity for many food crops, including rice[19]. Recently, Koraput has been declared by the Food and Agriculture Organization (FAO), Rome, as a global agricultural heritage site[13]. Since historical times, plants were collected from the forest, for food and medicine by tribal people who developed various processing methods according to their needs. With the onset of settled agriculture and modernization, this knowledge is being lost at a rapid pace, which may lead to reduced diversity of indigenous crops in this region[20]. Therefore, the focus of this study is to highlight the nutritional value of selected neglected and underutilized crop resources such as indigenous rice, millets, wild fruits and leaves and yam of Koraput for conservation and further utilization. It also indicates the importance of these indigenous species for food and nutritional security along with their climate-resilient characteristics.

Methodology

A mixed method of review approach was employed, comprising different research outcomes of the neglected and underutilized crop species used by different tribal people in Koraput. Information on underutilized crop resources was collected from several tribal communities of Koraput district. The data on consumption pattern and nutritional importance were collected through questionnaire, personal interviews with traditional healers and the published literature. This study on the nutritional and climate-resilient traits of indigenous rice, millets and wild yam is based on the synthesis of experiments carried out in our laboratory at the Central University of Odisha, Koraput or elsewhere.

Physiographic importance of the study site

Koraput is a tribal-dominated district of Odisha (18°14′–19°14′N lat. and 82°05′–83°25′E long.; Figure 1). This region is unique due to its topographic and ecological diversity with great variation in altitude (100–1672 m amsl). The district is predominantly inhabited by most of the primitive tribes, viz. Paroja, Bhumia, Gadaba, Bhatra, Durua and Kandha constituting about 50.6% of the total population[13]. Also, 72–83% of the people of this region live below the poverty line compared to 47% for Odisha and 26% for India[12]. Rainfall and temperature vary from 1320 to 1520 mm and 13.5°C to 40°C respectively, annually. This region comes under three agro-climatic zones: the Eastern Ghats highland zone, Western undulating zone and South Eastern Ghats zone[21].

Underutilized crop species for food and nutritional security

The plant genetic resources of Koraput are significant in the global context. There are nearly 79 angiosperms and one gymnosperm plant species endemic to the region[22,23]. The Swaminathan Research Foundation, Jeypore, Odisha has been taking a leading role in this region for enabling tribal and rural families to derive economic benefits from genetic resources. They have recorded 340 local varieties of rice, eight different species of minor millets, seven pulses species, five species of oilseeds and seven vegetable species in this region[22]. Table 1 shows some of the underutilized and wild crop species of Koraput with their nutritional importance.

Indigenous rice diversity of Koraput

Koraput region is famous for traditional rice landraces and is recognized as one of the centres of origin of Asian cultivated rice[24]. These local rice varieties show many primitive characteristics and have been traditionally cultivated by farmers using their traditional knowledge[25–27]. The diversity and genetic variation of rice germplasms in this region have been recorded by several researchers[24,25,28]. During 1955–1959, a total of 1745 germplasms of cultivated rice were collected by the ICAR-Central Rice Research Institute (CRRI), Cuttack, Odisha. After 40 years in 1995–1996 National Bureau of Plant Genetic Resources (NBPGR), New Delhi explored this region and collected 318 accessions[25]. Now-a-days due to modern agricultural practices and competition with high-yielding varieties, these vital genetic resources are being gradually eroded[28]. In spite of being less productive, traditional rice landraces ensure food and livelihood security of the tribal people due to several nutritional and agronomic traits[29]. Mishra and Chaudhury[19] reported that some of the indigenous

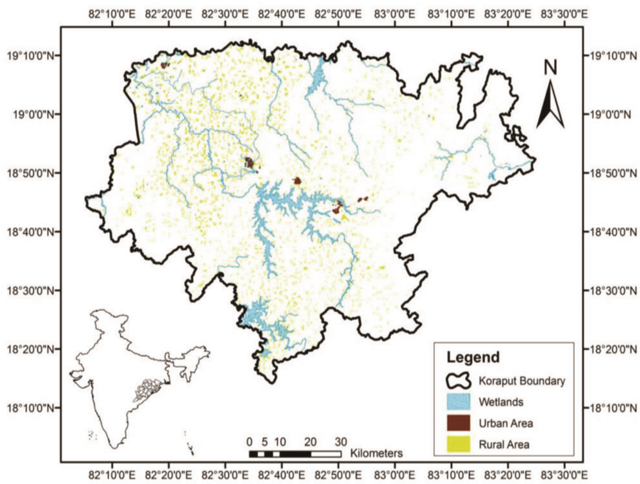

Figure 1. Map showing the study site Koraput district, Odisha, India.

Table 1. List of underutilized and wild crop species of Koraput for nutritional benefits

Crops	Underutilized species	Nutritional quality	Reference
Rice landraces	Machakanta, Haladichudi, Para Dhan, Muktabali, Sapuri Umuriachudi	Popular nutritious, non-sticky cooked rice, slender grain best for pulao and biryani	19, 26
	Kalajeera, Gangabali, Kuyerkuling, Deulabhoga, Lactimachi, Sapuri, Dudhamani, Muktabali and Nadiarasa	Popular aromatic and scented rice landraces	26, 27
	Bhatamalli, Kandulakath, Haladiganthi, Kalachudi Mallimakada, maligoindi, Beda Gurumukhi	Popular pigmented and medicinal rice landraces	31
Millets	Finger millet, foxtail millet, kodo millet, proso millet, little millet and sorghum millet	Superior nutritional, mineral and vitamin composition; higher physico-functional parameters	13, 19, 33
Wild edible tubers	*Dioscorea oppositfolia*, *D. hispida*, *D. hamiltoni*, *D. bulbifera*, *D. pubra*, *D. pentaphyla*, *D. wallichi* and *D. glabra*	Superior nutritional, mineral and antioxidant contents	35, 36
Wild edible leaves	*Butea monosperma*, *Bauhinia purpurea*, *Paederia foetida*, *Andrographis paniculata*, *Sterculia foetida*, *Cassioides*, *Meyma spinosa*	Better nutritional and health benefits	19, 23, 34
Wild edible fruits	*Buchanania lanzan*, *Carissa opaca*, *Careya arborea*, *Diospyros melanoxylon*, *Syzygium cumini*, *Mangifera indica*, *Artocarpus heterophyllus*, *Phoenix sylvestris*, *Schleichera oleosa*, *Madhuca indica*	Better nutritional and health benefits	19, 23
Wild flowers	*Indigofera pulchella*, *Cordia oblique*, *Sesbania grandiflora*, *Woodfordia fruticose*, *Tamarindus indica*, *Madhuca indica* and *Azadirachta indica*	Good nutritional and health benefits	23

rice landraces such as Machhakanta, Haladichudi, Paradhan, Muktabali, Sapuri and Umuriachudi hold superior grain quality along with cooking and nutritional quality (Table 1). Arunachalam *et al.*[26] and Roy *et al.*[27] studied different aromatic rice landraces such as Kalajeera, Gangabali, Kuyerkuling, Deulabhoga, Lactimachi, Sapuri, Dudhamani, Muktabali and Nadiarasa of this region and claimed that they have superior aroma along with grain quality traits. Genetic variation of seed quality traits was observed among these genotypes; notably the 'Sapuri' variety showed highest seed length and width ratio (3.57 ± 0.06) with best quality seeds of this locality. The varieties 'Muktabali' and 'Kuyerkuling' showed the highest protein content (4.50 ± 0.03 mg/g) and 'Dudhamani' variety showed the highest starch content (803 ± 20 mg/g) among traditional varieties compared to the modern aromatic variety 'Sugandha' (CR 907)[30]. Edwina *et al.*[31] studied the biochemical and antioxidant activities of several popular pigmented rice landraces such as Bhatamalli, Kandulakath, Haladiganthi, Kalachudi, Mallimakada, Maligoindi, Beda Gurumukhi of Koraput. The amylose, total anthocyanin and phytate contents of these landraces ranged from 22.01% to 44.38%, 28.73 to 193.36 mg/100 g and 1.16 to 24.49 mg/100 g respectively. Phenol, polyphenol and antioxidant capacity varied from 233.92 to 251.38 mg/100 g, 252.43 to 284.36 mg/100 g and 19.37% to 38.10% respectively. Maganti *et al.*[32] reported variation of iron and zinc contents among traditional rice genotypes of this region. They found that landraces such as Raskadam, Machhakanta and Haldichudi contain greater than 15.1 mg/kg of iron and 25.1 mg/kg of zinc along with higher accumulation of micronutrients. Some of the local rice landraces also exhibited higher content of calcium, iron and zinc[31]. The highest calcium (635 mg/100 g) and zinc (8.67 mg/100 g) contents were found in Paradhan and iron (38.5 mg/100 g) in Malligoindi variety. These landraces can provide nutritive and health benefits for rice-based diets.

Indigenous millet diversity of Koraput

Koraput is also famous for minor millets which are conventionally grown and consumed by tribal farmers. In Koraput, finger millet is cultivated in about 16% of the total gross cropping area[12]. Different millet species are cultivated by tribal communities having varied duration of maturity and grains with variation in shape, size and colour under multiple cropping systems[19]. They have been cultivating indigenous millet varieties, importantly *Eleusine coracana* (L.) Gaertn., *Panicum sumatrense* Roth. ex Roem. et Schult. and *Setaria italica* (L.) P. Beauv. The tribal people frequently use different millets and employ various processing methods in accordance to their needs and traditional use[19]. Panda *et al.*[33] studied the bioavailability of nutrients in different indigenous millets of Koraput to promote their utilization and bioprospecting. The proximate composition such as ash, crude fibre and crude fat of millet flours varied from 1.4% to 4.0%,

Table 2. Nutritional superiority of wild yam species of Koraput over cultivated species (*Dioscorea alata*)[35,36]

Parameter	*Dioscorea oppositifolia*	*Dioscorea hamiltonii*	*Dioscorea pubera*	*Dioscorea wallichii*	*Dioscorea alata*
Ash content (%)	4.39 ± 0.33	5.42 ± 0.43	4.24 ± 0.48	3.82 ± 0.24	3.16 ± 0.21
Crude fat (%)	1.62 ± 0.03	1.90 ± 0.08	1.55 ± 0.03	0.91 ± 0.16	0.91 ± 0.02
Crude fibre (%)	1.52 ± 0.01	1.45 ± 0.06	1.60 ± 0.12	2.02 ± 0.01	1.40 ± 0.02
Carbohydrate (%)	25.30 ± 0.41	22.97 ± 0.35	26.66 ± 0.89	21.87 ± 0.52	24.07 ± 0.70
Crude protein (%)	9.50 ± 0.23	9.77 ± 0.11	10.28 ± 0.10	8.38 ± 0.25	8.78 ± 0.13
Gross energy (kcal)	153 ± 1	148 ± 2	161 ± 2	129 ± 2	139 ± 2
Vitamin-C (mg/100 g)	5.67 ± 0.01	5.66 ± 0.17	9.42 ± 0.23	5.36 ± 0.34	5.01 ± 0.24
Vitamin-E (mg/100g)	0.55 ± 0.06	0.66 ± 0.03	0.57 ± 0.01	0.40 ± 0.04	0.36 ± 0.03
Diosgenin (mg/100 g)	4.15 ± 0.10	4.85 ± 0.21	6.66 ± 0.04	4.89 ± 0.15	3.75 ± 0.07
Phytate (mg/100 g)	4.60 ± 0.30	4.49 ± 0.27	4.27 ± 0.08	4.47 ± 0.35	3.21 ± 0.04
Oxalate (mg/100 g)	0.172 ± 0.008	0.159 ± 0.007	0.150 ± 0.003	0.156 ± 0.002	0.138 ± 0.008
Sodium (mg/100 g)	60.33 ± 1.87	89.42 ± 0.98	67.24 ± 1.85	68.41 ± 1.89	55.06 ± 1.16
Potassium (mg/100 g)	1248 ± 4	1029 ± 6	1140 ± 4	1161 ± 4	989 ± 5
Iron (mg/100 g)	26.61 ± 0.27	28.61 ± 0.85	24.18 ± 0.62	17.09 ± 0.57	19.75 ± 0.24
Calcium (mg/100 g)	52.32 ± 0.33	46.17 ± 0.20	74.79 ± 0.40	69.28 ± 0.31	43.13 ± 0.16
Zinc (mg/100 g)	4.70 ± 0.27	3.60 ± 0.31	6.21 ± 0.18	5.45 ± 0.33	3.43 ± 0.21
Phosphorus (mg/100 g)	235.37 ± 2.01	214.63 ± 1.85	248.27 ± 2.00	213.93 ± 2.35	218.20 ± 1.64

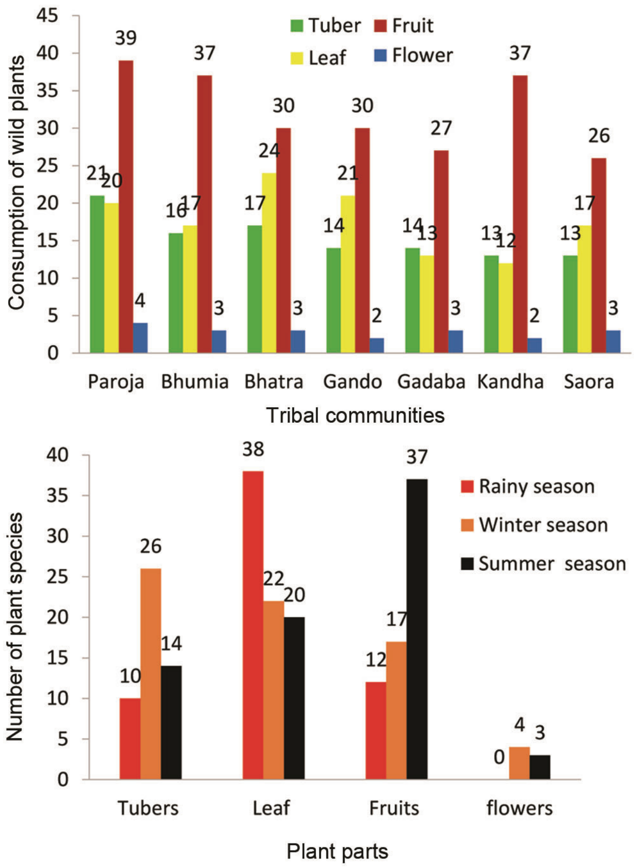

Figure 2. Tribal-specific consumption patterns and seasonal availability of wild edible plants in Koraput[23].

2.0% to 11.0% and 1.1% to 3.6% respectively. The nutritional parameters significantly varied among the genotypes: sugar (8.3–25.4%), starch (51.6–69.1%), amylose (5.2–12.5%) and protein (9.3%–14.3%). Potassium and sodium contents ranged from 227.4 to 441.2 mg and 10.30 to 11.05 mg per 100 g dry wt respectively[33]. Some traditional millets are having lower levels of sodium compared to potassium, which suggests that these are advantageous for health.

Wild edible plant diversity of Koraput

Padhan and Panda[23] documented the usage of 156 wild plant species by tribal people of Koraput for food and medicine. Figure 2 presents the tribal-specific consumption patterns of different wild plant species. The wild species most consumed by the tribals are wild fruits (39) followed by leafy vegetables (24), tubers (21) and flowers (4). Paroja tribe uses more wild resources compared to the other tribes. They collect mainly wild tubers in winter season and green leaves in the rainy season. Wild fruits and flowers are mainly collected during winter and summer seasons. Mishra and Chaudhury[19], and Mahapatra and Panda[16] reported different wild fruits and berries having a significant role in the food habit of tribal people of Koraput (Table 1). Usually oil is extracted from the seeds of *Madhuca indica*, *Azadirachta indica* and *Schleichera oleosa* and commercialized. More importantly, these species need to be promoted as a natural source of antioxidants and nutraceuticals. Different tribal groups also used various leafy vegetables (Table 1). Different leafy vegetables are widely distributed in the rainy season in open fields or agricultural fields. Misra[34] highlighted the nutritional and antioxidant properties of wild leafy plants and their potential for better health and nutrition. The leafy vegetable *Moringa oleifera* (6.6%) showed highest crude protein and highest total lipid (0.013 mg/g) content, whereas vitamin B1 was superior in *Glinus oppositifolius* (0.0015 mg/g). Table 1 also shows the list of flowers used by various tribes and their consumption patterns. Wild yam species are popular and used as food by the tribals of Koraput. These include *Dioscorea bulbifera* L., *D. glabra* Roxb., *D. hamiltonii* Hook.f., *D. hispida*

Table 3. List of underutilized and wild crop species of Koraput for climate resilience

Crop	Underutilized species	Climate-resilient traits	Reference
Rice landraces	Machhakanta, Kalajeera, Pandakagura, Mugudi, Haladichudi and Dangarbayagundar	High level of tolerance to drought stress	29, 39, 41
	Samudrabali, Basnamundi, Gadaba, Surudaka and Dokarakuji	High level of tolerance to flash flood and stagnant flooding; better survival than check variety FR13A during flooding	42, 44
	Bausaganthi, Patadhan and Basantichudi	High degree of anaerobic germination potential suitable for direct sowing	43
	Kalajeera, Machhakanta and Haladichudi	High level of tolerance to multiple stresses (drought, salinity and flooding)	40
	Kalajeera, Machhakanta and Haladichudi	Superior leaf photosynthetic capacity, stomatal traits, water-use and carboxylation efficiency	11, 41
Finger millet	Jhana, Lala, Kurkuti, Ladu, Bhadi and Taya	Superior leaf photosynthetic and stomatal traits, water-use and carboxylation efficiency and shows adaptive mechanism to cope with changing environment	12, 46
	Telenga mandia and Dasara mandia	Most climate-resilient characters such as biotic and abiotic stress tolerance, pest resistance and low input requirement.	45

Dennst., *Dioscorea oppositifolia* L., *D. pentaphylla* L., *D. pubera* Blume. and *D. wallichii* Hook.f.[35]. Table 2 presents the nutritional properties of wild and cultivated yam tubers of Koraput. The proximate composition of wild yam tubers ranged from 3.82% to 5.42% ash, 1.55% to 1.90% fat, 1.45% to 1.60% fibre, 22.9% to 26.6% carbohydrate, 9.5% to 10.2% protein, and 148 to 163 kcal gross energy in comparison to the cultivated species (*D. alata*), i.e. 3.16% ash, 0.91% fat, 1.40% fibre, 24.07% carbohydrate, 8.78% protein and 139 kcal gross energy (Table 2). Wild yam tubers such as *D. pubera*, *D. hamiltonii* and *D. oppositifolia* showed superior mineral and nutritional contents than cultivated yam[35]. The micronutrient composition ranged from 60.33 to 89.4 mg/100 g of sodium, and 1029 to 1248 mg/100 g of potassium compared to 55.06 mg/100 g of sodium and 989 mg/100 g potassium in the cultivated species[35]. Padhan *et al.*[36] studied the tuber quality and safety concerns about wild yam tubers, and reported that majority of these tubers are superior in essential minerals like calcium (18.08–74.79 mg/100 g), iron (11.15–74.79 mg/100 g), zinc (2.11–6.21 mg/100 g) and phosphorus (179–248 mg/100 g). The level of antinutrients such as diosgenin, phytate and oxalate in raw tuber was significantly higher in wild than cultivated tubers[36]. However, it was also reported that the antinutrient level was lower than that recommended by World Health Organization[36]. The wild yam tubers have 2.19–9.62 mg phenol, 0.62–0.85 mg flavonoid and 1.63–5.59% antioxidant capacity with higher free radical scavenging activity. They possess superior antioxidant capacity and can be a natural source of antioxidants[37,38].

Underutilized crop species for climate resilience

Table 3 shows the list of underutilized wild crop species of Koraput for climate resilience and their useful agronomic traits. Mishra *et al.*[29] identified six local rice landraces, viz. Haladichudi, Machhakanta, Kalajira, Mugudi, Pandakagura and Dangarbayagundar with high level of tolerance to drought stress by laboratory screening. On the basis of physiological introspection, three landraces (Haldichudi, Kalajeera and Machhakanta) showed superior photosynthesis and maintenance of higher water-use efficiency under drought condition than the tolerant check variety N22 (ref. 39). This result supplemented with molecular characterization based on drought tolerance QTL-linked SSR markers revealed that these landraces are more diverse, and the presence of one or more drought-tolerance-linked QTL. In addition to drought tolerance, these landraces showed higher degree of tolerance to multiple stresses like salinity and flooding stress[40]. The grain yield of Kalajeera (22–25 q/ha), Machhakanta (25–30 q/ha) and Haladichudi (18–20 q/ha) was less than that of modern high-yielding varieties IR 42 (65–67 q/ha) and IR 64 (58–61 q/ha). The stomatal triats such as stomatal density and stomatal index of these landraces were superior compared to the high-yielding hybrid varieties (Table 4). They show higher resilience to the prevailing environment because of efficient gas exchange and stomatal traits[11,41]. After a rapid flooding tolerance screening of more than 88 lowland rice landraces from Koraput region, Basnamundi, Gadaba, Dokarakuji, Samudrabali and Surudaka were identified as the flooding-tolerant varieties of the region[42]. Moreover, three landraces, namely Basnamundi, Gadaba and Samudrabali showed better survival rates (97–98%) than international flooding-tolerant check variety FR13A (95%; Table 3). For lowland rice-growing areas affected by long-term flooding, these landraces are suitable for cultivation because for their better survival and elongation under water[43]. It has also been revealed by molecular genotyping studies that these landraces contain flooding tolerance

Table 4. Yield and climate-resilient traits of traditional rice and millets from Koraput over modern, high-yielding variety

Variety	Yield (q/ha)	Photosynthetic rate (μmol CO_2 m^{-2} s^{-1})	Stomatal conductance (mMol H_2O m^{-2} s^{-1})	Water-use efficiency	Carboxylation efficiency	Stomata density (no. mm^{-2})	Stomatal index
Rice*							
Kalajeera (Landraces of Koraput)	22–25	17.55 ± 1.6	91.7 ± 4.06	4.91 ± 0.19	0.065 ± 0.003	347.64 ± 20.8	7.76 ± 0.36
Haldichudi (Landraces of Koraput)	18–20	17.37 ± 0.5	88.1 ± 4.25	5.12 ± 0.10	0.063 ± 0.008	318.82 ± 20.8	6.02 ± 0.20
Machakanta (Landraces of Koraput)	25–30	17.51 ± 1.0	89.2 ± 7.43	5.38 ± 0.11	0.066 ± 0.001	323.52 ± 21.5	5.81 ± 0.61
IR 64 (hybrid variety)	58–61	14.85 ± 0.4	83.1 ± 1.90	4.18 ± 0.22	0.052 ± 0.003	264.70 ± 11.5	4.35 ± 0.33
IR 42 (hybrid variety)	65–67	15.02 ± 1.0	82.4 ± 1.34	4.62 ± 0.16	0.054 ± 0.007	294.11 ± 21.5	4.37 ± 0.21
Finger millet**							
Jhana (Landraces of Koraput)	18.0	19.18 ± 0.19	77.64 ± 1.52	4.96 ± 0.14	0.14 ± 0.003	43.74 ± 3.83	30.30 ± 1.28
Lala (Landraces of Koraput)	16.0	15.42 ± 0.12	57.07 ± 1.70	4.68 ± 0.01	0.10 ± 0.003	43.74 ± 3.83	29.29 ± 1.01
Kurkuti (Landraces of Koraput)	21.2	10.43 ± 0.14	52.21 ± 1.21	3.96 ± 0.16	0.08 ± 0.002	43.74 ± 3.83	23.30 ± 0.31
Ladu (Landraces of Koraput)	17.2	11.63 ± 0.18	52.95 ± 1.42	3.55 ± 0.23	0.08 ± 0.005	31.24 ± 3.83	23.14 ± 1.60
Taya (Landraces of Koraput)	20.5	17.61 ± 0.93	39.69 ± 1.41	5.86 ± 0.32	0.08 ± 0.01	43.74 ± 3.83	27.92 ± 0.91
Bhairabi (high yielding variety)	27.5	13.99 ± 0.67	43.52 ± 0.62	3.60 ± 0.24	0.07 ± 0.005	38.74 ± 1.76	22.79 ± 2.52

*Panda *et al.*[11]; **Panda *et al.*[41].

gene *Sub 1* as in FR13A. Along with the flooding tolerance, three rice landraces (Basantichudi, Bausaganthi and Patadhan) have been identified as having superior anaerobic germination potential[44]. These landraces are associated with efficient carbohydrate management and coleoptile elongation than the tolerant check variety. Despite their poor phenotypes, these traditional landraces are identified as potential genetic resources for climate-resilient breeding programmes and can be popularized globally.

Telugu mandia and Dasara mandia have been identified as the best climate-resilient millet varieties of this region[45]. Panda *et al.*[46] collected different local finger-millet genotypes from Koraput to evaluate their genetic diversity and study variability in morphological traits among them. The findings indicate that in spite of less productivity, these varieties show better agronomic traits and resistance to biotic and abiotic stresses. Some local finger-millet genotypes such as Kurkuti, Lala, Ladu, Jhana and Taya showed superior photosynthetic capacity, water-use efficiency and carboxylation efficiency compared to the other genotypes (Table 4). They also showed better stomatal density and stomatal index, and exhibited better coping mechanism with changing environment[46]. To popularize millet production in Koraput region, Pradhan *et al.*[12] studied the pattern of crop productivity, labour requirement and profitability along with nutrition awareness initiatives among the tribal communities. They have suggested better agro-management practices that improve millet production and are suitable for climate-smart agriculture.

Koraput farmers reported that during the cyclone Hudhdud in October 2014, most of the paddy and millet fields were affected and the plants were blown down due to heavy winds, but some of the traditional landraces of rice and millets could survive the fury of the cyclone[47]. Choudhury[48] also reported that native rice varieties of Koraput such as Kolamali and Kaberigandha survived better than the modern varieties during the cyclones Philine and Hudhud that hit the Odisha coast in 2013 and 2014 respectively. The complete loss of paddy crops during the supercyclone in Odisha in October 1999 resulted in loss of confidence in high-yielding varieties among farmers, forcing them to switch back to traditional varieties which gave 30–40% higher yield[49]. In Koraput, climate variables such as temperature and rainfall have been studied from 1980 to 2016 by Panda *et al.*[50]. They noted that climate variations and loss of monsoon rainfall have a significant negative impact on crop yield. Under climate variable conditions, traditional landraces of rice and millets showed more adaptive responses and gave better yield. Thus, these traditional landraces are potential genetic resources for climate-resilient breeding programmes.

Conclusion

It is evident from the present study that tribal communities of Koraput largely cultivate and depend on traditional and wild crop resources for their food and livelihood. The superior indigenous gene pool of rice and millets identified should be popularized for climate-resilient breeding programmes. For alleviating hunger and malnutrition, the less familiar wild plants such as wild fruits, leaves and yam are a good alternative source of food. Necessary steps should be taken for mass consumption, domestication and to conserve these valuable wild crop resources in their natural habitat. A strategy to promote commercial production of these indigenous rice, millet and wild yam plants is required to boost the local economy by initiating processing, value addition and creating a market so as to reach more consumers. Above all, we must create mass awareness on the importance of wild and neglected crop resources of Koraput and their conservation for a sustainable future.

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