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ORIGINAL PAPER

Increased farmer willingness to pay for quality cassava (*Manihot esculenta* Crantz) planting materials: evidence from experimental auctions in Cambodia and Lao PDR

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Abstract
Varietal turnover is a major mechanism for farmer adaptation to rapidly changing environmental and market conditions. Understanding factors related to varietal turnover is critical for safeguarding food security in the face of increasingly rapid changes to production contexts. Preference elicitation methods like experimental auctions reveal farmers' willingness to pay (WTP) for seeds with different characteristics. We engaged farmers growing cassava (*Manihot esculenta* Crantz) across a wide geographic scope in Cambodia (n = 321, 4 provinces) and Lao PDR (n = 391, 5 provinces) in modified second-price experimental auctions to determine WTP for three cassava seed classes: farmer-produced planting stems of an undescribed variety, farmer-produced planting stems of an elite variety with lower susceptibility to Cassava Mosaic Disease (CMD), and virus-free tested planting stems of the same elite variety. In Lao PDR, mean auction bids for a bundle of 20 planting stems were 0.54, 0.92, and 1.40 USD for farmer, elite, and elite tested stems, while in Cambodia the analogous mean bids were 0.58, 0.77, and 1.16 USD, respectively. A significantly higher WTP associated with elite variety and tested stems in both countries was influenced by both geographic location (province) and individual socioeconomic farmer characteristics. In Lao PDR this included lower WTP of women, higher WTP of ethnic minorities, and, for improved stems, lower WTP of farmers with increased cassava growing experience. In Cambodia fewer socioeconomic variables affected WTP. Our results indicate significant increases in WTP for clean planting materials and new varieties, supporting market-based clean seed approaches as a component of regional control strategies for the CMD epidemic currently threatening a global agri-food value chain.

Keywords Experimental auctions · Willingness to pay · Seed quality · Crop variety · Preference elicitation · Vegetatively propagated crops

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1 Introduction

1.1 Experimental auctions as a window on seed demand

In the context of agricultural production seed can be functionally defined as any biological materials used to grow crops. Seed is the most important vehicle for varietal adaptation to ensure global food security under rapidly changing conditions. Despite large investments and technological progress in the development of improved seeds, adoption in developing countries is often low and highly heterogenous (Almekinders et al., 2019; O'Gorman & Pandey, 2010; Singh et al., 2020).

Vegetatively propagated crops (VPCs) are vital contributors to global diets and incomes with increasing production

worldwide (Thiele et al., 2022, pp. 5–9), but differ functionally from most grains, cereals, and legumes by their clonal mode of propagation (Andrade-Piedra et al., 2022). Vegetative propagation empowers farmers to directly multiply and exchange preferred varieties, giving VPC seed systems formidable impact potential through dissemination of improved crop genetics. However, these same characteristics also present a pathway for transgenerational transmission and accumulation of pests and diseases (McEwan et al., 2021; Shepard & Claflin, 1975). The vegetative reproduction, perishability, high water content, and higher physiological activity of VPC seed exacerbates degradation during harvest, transport, and storage, which combines with varietal stability to result in primarily informal, decentralized seed systems (Bentley et al., 2020). Many farmers growing VPCs predominantly use their own seed, and acquire planting materials off-farm through free exchange, as a gift, or by barter, relying on social relationships in the informal seed system. This dominance of farmers' non-commercial sourcing of seed may present a barrier to efficient varietal turnover. Evaluation of informal cassava seed networks have found seed commercialization nevertheless to be common in cassava, with cash sale frequently observed in locales as diverse as Nigeria (Pircher et al., 2022; Teeken et al., 2018), Rwanda (Kilwinger et al., 2021), and Vietnam and Cambodia (Delaquis et al., 2018).

The underdevelopment of methods for evaluating farmer seed demand has been highlighted as a general challenge of seed systems research (Almekinders et al., 2019), and a particularly problematic gap for VPC seed systems (McEwan et al., 2021). Willingness to pay (WTP), conceived of as the maximum price a buyer accepts to pay for a good or service (Le Gall-Ely, 2009), is one of the most used metrics in consumer research. Rather than relying on stated preferences, experimental methods to 'reveal' the WTP of participants place them in scenarios in which a) truthful appraisal of their real intentions is incentivized as the rational course of action, and b) there are real consequences for the decision (or at least a probability thereof).

We evaluated farmers' WTP for cassava planting stems (the woody planting materials serving as 'seed' for cassava propagation) representing (a) farmer stems of an uncertain variety, comparable to what would be available in a district market, (b) farmer stems of an elite variety with reduced CMD susceptibility, and (c) disease-free (tested) stems of the same elite variety in Cambodia and Lao PDR using an adapted second price, sealed bid group experimental auction mechanism combined with a participant socioeconomic survey. We provide WTP measures for cassava planting materials in a context with little pre-existing seed market information or reference sources, assess purchase behaviors, and use regression analyses to examine how individual, household and farm socioeconomic characteristics influence WTP for cassava stem products with different quality traits.

1.2 Setting and context: cassava in Southeast Asia

Estimations of revealed WTP are especially important in the case of cassava, a crop with challenges in the development of market responsive seed systems including long lead times for quality seed production because of low stem multiplication ratios, and high stem volume and weight making transport expensive. Southeast Asia's commercially oriented cassava sector supports a multi-billion USD industrial value chain with millions of participating smallholders (Wiebe et al., 2021), is one of five priority crop commodities in the 2020 – 2025 regional food security strategy (ASEAN, 2020), and forms the basis of one of the biggest carbohydrate export industries underpinning global food systems (Parmar et al., 2017). Cassava production in Southeast Asia's Greater Mekong subregion (GMS) consists of a highly commercial production and marketing system based on smallholder cultivation. Despite this, stem production and delivery mechanisms routinely supplying cassava varieties to smallholders remain nearly entirely informal (Delaquis et al., 2018). Destined for industrial chip or starch processing markets, Southeast Asian cassava varieties are primarily valued for high fresh root yield, starch content, and plant architecture attributes which reduce farm labor and ease operations, such as reduced branching, or rooting patterns less recalcitrant to manual harvesting. The characteristics of cassava for use as a primary industrial ingredient contrast strongly with those in Africa or Latin America, where the use of cassava and its processed products for home consumption emphasize sensory attributes (Agre et al., 2017; Alvarado et al., 2013; Awoyale et al., 2021). These differences in target attributes have driven Asian public breeding programs to release elite, industrial varieties with almost exclusive emphasis on yield and starch content (Malik et al., 2020). In this cash crop context, stem cost has been identified as the primary limiting factor in the production economics of smallholder cassava producers in Lao PDR (Soukkhamthat & Wong, 2016).

Cassava mosaic disease (CMD) was detected in Southeast Asia for the first time in 2015 (Wang et al., 2016). The causative agent, Sri Lanka Cassava Mosaic Virus, spread rapidly in Cambodia (Minato et al., 2019), Vietnam (Uke et al., 2018), China (Wang et al., 2018), Thailand (Siriwan et al., 2020), and Lao PDR (Chittarath et al., 2021). Although other cassava pathogens were already present in the region (Graziosi et al., 2016), the novel and aggressively invasive qualities of CMD, in tandem with the continental epidemic impact of the disease caused by related virus species in Africa (Legg & Thresh, 2003) triggered alarm in Southeast Asia.

In addition to the presence of insect vectors, the spread of cassava viral diseases has been linked to high rates of stem-borne infection (Szyniszewska et al., 2017; Zinga et al., 2013) and efficient informally regulated seed exchange networks (Delêtre et al., 2021; Legg et al., 2015). First appraisals of regional cassava seed networks in the GMS describe frequent exchanges over both short and long distances (Delaquis et al., 2018), but further characterization remains limited in most countries in the region.

1.3 Willingness to pay and experimental auctions

Many seed business approaches involve marketing seeds with superior quality attributes compared to informal market alternatives for a premium price. For the development of sustainable early generation seed production strategies, market price dynamics and factors contributing to WTP are therefore important research targets. Information about seed quality is commonly considered a constraint for farmers in developing countries in making choices about seed use. Farmers faced with novel seed market products often experience information asymmetry, but there are mixed reports about whether, and how, this translates to changes in WTP (Fuglie et al., 2006; Mastenbroek et al., 2021; Wossen et al., 2022).

Stated measures of WTP obtained through methods such as survey questionnaires or focus group discussions are often considered unreliable and inaccurate; nevertheless, they remain common in practice (Blankenship et al., 2019; Roder et al., 2019), likely due to ease of implementation. An alternative is the use of revealed preference methods, including auctions, as tools to elicit consumer demand for products or attributes thereof (Banerji et al., 2016; Canavari et al., 2019; Horna et al., 2007; Kassie et al., 2017).

The theory of consumer behavior (Lancaster, 1966) states that consumers attribute value based on perceptions of quality in particular attributes of goods, leading to higher WTP. Some seed quality attributes are more difficult for farmers to evaluate than others, leading to the use of labeling approaches like certification schemes to render quality attributes which are not directly observable ('credence' attributes), observable to the consumer via quality assurance statements or certification labels (thus becoming observable 'search' attributes) (Auriol & Schilizzi, 2015; Darby & Karni, 1973).

The relevant quality attributes of seed most frequently appearing in the auction literature are variety and phytosanitary quality. Depending on seed physiology, disease symptom expressions, and farmer experience, either or both could be considered as credence attributes. Although the application of experimental auctions to assess WTP for seeds remains relatively limited (Pircher & Almekinders, 2021), there is evidence that auction results do more accurately reveal farmer seed preferences than stated measures (Waldman et al., 2014). Growing interest in auction methods has led to recent applications of nth price auction methods with sweetpotato produce (Collart et al., 2019), common bean varieties (Waldman et al., 2014), potato varieties (Okello et al., 2018) and seed classes (Maredia & Bartle, 2023), quality of bean and cowpea seeds (Maredia et al., 2019), and the absence or use of seed preservative treatments (Morgan et al., 2020). The most commonly applied of these approaches in the broad sense is the second price, or 'Vickrey' auction, in which the participant with the highest bid is the auction 'winner' but is only required to pay the second highest price; a process which incentivizes truthful bidding (Canavari et al., 2019; Lucking-Reiley, 2000; Vickrey, 1961). There are however concerns that in particular contexts where commercial seed sourcing is relatively uncommon, the use of auctions faces limitations (Kilwinger, 2022).

1.4 Farmer use of cassava planting materials

Farmers may purchase seed to achieve different goals, including establishment of new plantations, whole or partial crop area replacement, achieving varietal diversification or change, pilot testing, or establishment of subplots for self-multiplication (Navarrete et al., 2023; Zeven, 1999). Little is known about cassava varietal identity and perceptions thereof in Cambodia and Lao PDR, and neither country has ever conducted a varietal survey based on genetic information at interprovincial / national scale. However, low varietal diversity is characteristic of cassava farming in the region (Delaquis et al., 2018; Ocampo et al., 2022), and farmers appear in general to face difficulties in identification of cassava varieties, exposing seed buyers to risks associated with information asymmetry which may contribute to variability in WTP (Latacz-Lohmann and Van der Hamsvoort, 1997).

Neither Cambodia nor Lao PDR has a domestic cassava breeding program, leaving them reliant on introductions of new varieties from breeding programs in neighboring Thailand and Vietnam through both formal channels (until 2010–2015) and informal introductions (after 2015). Despite confusion among multiple local names for the same variety, the main elite varieties have some distinguishing characteristics (petiole color, apical leaf color, stem color, root shape, etc.) that farmers may generally associate with preferred traits. However, the situation is complicated when farmers can't see the mature plant before purchase, denying them reliable visual cues for distinguishing varietal identity. To add to the confusion, the rapid release of CMD resistant varieties is greatly increasing the complexity of farmer seed choice by quickly increasing the number of available varieties in addition to the extra consideration of disease resistance as a selection characteristic.

Subsidy is a commonly recommended option for serving marginalized populations with low WTP for seed (Maredia et al., 2019), but this comes with the risk of distorting or supplanting emerging local seed markets. When employed, care should be taken to ensure that subsidies reach the right people and do not further deepen disparities; for this, understanding local social dynamics and trends in need and demand within local populations is an essential need (Delaquis & Almekinders, 2020).

1.5 Ethnicity, gender, and place

Ethnicity, gender and place are strong candidate variables that may influence the use and importance of cassava, seed sourcing practices, the demand for seed, and willingness to pay for it. There are several reasons to suggest the importance of these variables in both Cambodia and Lao PDR. With rare exception (notably the Cham in the Southeast), Cambodia's population is dominated by a single self-identified ethnolinguistic group, the Khmer. Cambodian ethnic minority populations were persecuted severely during the genocide perpetuated by the Khmer Rouge regime (1975–1979), greatly reducing their numbers and attempting systematic erasure of their ethnic identities (Jacobs, 2022). The 2019 Cambodian census identified only 2.9% of the population speaking an ethnic minority language as a mother tongue (National Institute of Statistics, 2019), and 100% of the responses in our survey self-identified as Khmer. Gendered differentiation is apparent between livelihood activities, although joint household decision-making is common in many agricultural activities including crop choice (Sumner et al., 2017). In rural areas of Cambodia, higher paying wage labor jobs associated with mobility and machinery operation tend to be dominated by men, with women taking on primary roles in reproductive labor, and household duties including caring for relatives (Joshi, 2020).

In contrast, Lao PDR's ethnic minority populations include dozens of ethnic groups comprising together half of the country's total population (Lao Statistics Bureau, 2015). Ethnicity is complex in Lao PDR, incorporating elements of precolonial, colonial, geospatial, and ethnolinguistic classification schemes (Schlesinger, 2003). Despite attempts by groups including the Lao Front for National Construction to offer comprehensive groupings based on linguistic and cultural similarities (IFAD, 2012), many Lao still self-identify using an informal three-category system. We avoided debates on classification schemes by maintaining only two groups based on self-identification: the majority Lao ethnolinguistic group and the remainder. Larson et al. (2020) reported that in a game-based approach Lao women more readily adopted a new rice variety, while Moglia et al. (2020) reported women agreed more often that the price they paid for rice seed was fair than men. Interactions between geographic and market contexts and gender have been emphasized in the adoption of rubber cultivation in remote northern Lao PDR (Kusakabe & Chanthoumphone, 2021), while studies have noted that despite high reported levels of joint household decision-making, the labor burden of newly adopted crops in Lao PDR disproportionately affected women (Park & Daley, 2015).

1.6 Objectives

We employed a second price experimental auction approach to elicit revealed WTP for cassava planting materials with known and unknown varietal and phytosanitary status in the context of the unfolding CMD epidemic. We asked:

1. What is the farmer WTP for cassava planting materials of three different statuses (farmer stems of unknown variety and phytosanitary status, an elite variety less susceptible to CMD but of unknown phytosanitary status, and the same elite variety tested and disease free)?
2. What socioeconomic characteristics of participants impact WTP for these products? And how that may these be associated with differences between and within contexts in Cambodia and Lao PDR?

Our research presents comprehensive measures of WTP for cassava stems across the major cassava production environments in Cambodia and Lao PDR, and contributes to the wider literature on the use of experimental auctions for seed. We discuss the implications of these findings for the establishment of clean seed systems in the GMS of Southeast Asia.

2 Methodology

2.1 Site and participant selection

Study sites were selected in the major cassava production areas of Cambodia and Lao PDR, identified via nationally reported 2018 district agricultural statistics in both countries, in consultation with national agricultural research authorities (the Cambodian Agricultural Research and Development Institute, and the National Agriculture and Forestry Research Institute in Lao PDR) (Fig. 1).

Table 1 lists details of the selected auction locations, covering the major cassava production regions of each country. Villages within selected districts were chosen based on discussions with national officials to ensure that study sites were accessible, with sufficient concentrations of cassava producers to accommodate auction group size requirements. Groups of 20 participants per village were assembled with the assistance of district officials and village heads, who

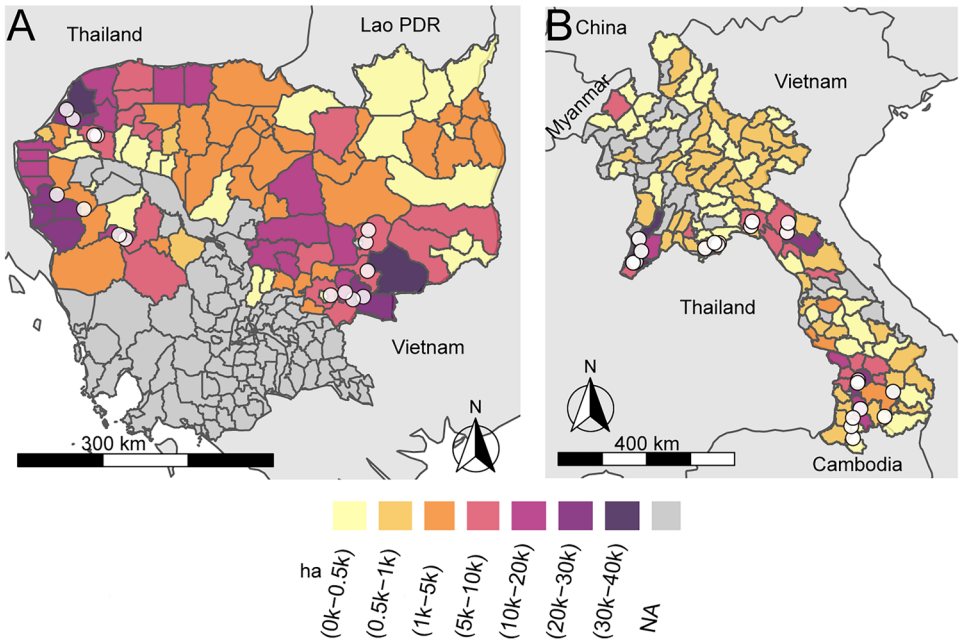

Fig. 1 Auction sites (white circles) in the 2020–2021 and 2021–2022 planting seasons in Cambodia (**A**), and Lao PDR (**B**). Background shade indicates area of cassava production by district in each country. Source: authors

produced village member lists ahead of the event, alerting potential participants to join the following morning, limited to one participant from each household. The only participant selection criterion was active participation in cassava cultivation, with participants selected randomly from the pool of attendees by the auction staff, endeavoring to maintain a representative gender and age balance in the sample.

2.2 Experimental treatments

We employed a single round, second price, sealed bid auction mechanism. Product details are presented in Table 2, and are henceforth referred to as P1, P2, and P3. Treatments were designed to establish comparisons between the characteristics of the three products. Information was presented to the group on both the varietal characteristics of the products, and information about the presence and the spread of CMD in the region. Because of the highly variable physical qualities of cassava stems, and the credence nature of the attributes evaluated, all products were represented in auctions by the Thai variety KU50, which is popular in many areas of the GMS (Ocampo et al., 2022), and has been found to be least susceptible to CMD symptom expression and yield loss among available elite breeding program releases (Malik et al., 2022). In this context, 'elite' indicates both high reported yields from multilocation trials and this reduction in susceptibility to CMD, and 'clean' stems represent those originating from multiplication fields that are subject to regular PCR-based testing and visual inspection. Mature stems were harvested from experimental fields located in

Table 1 Location, number of auctions (Auctions), number of participants (n), and province estimate of ethnic minority population for experimental cassava stem auctions implemented in Cambodia and Lao PDR in the 2020–2021 and 2021–2022 planting seasons, respectively (see article Supplementary Information for a complete village list)

Country	Provice	Districts	Ethnic majority (%)[a]	Auctions	n
Cambodia	Banteay Meanchey	Preah Net Preah	> 95	4	80
Cambodia	Battambang	Banan, Rukhak Kiri, Ratanak Mondul	> 95	4	81
Cambodia	Tboung Khmum	Dambae, Tboung Khmum, Memot	> 95	4	80
Cambodia	Kratie	Chhloung, Chet Borei	> 90	4	80
Lao PDR	Attapeu	Samakhixay, Sanamxay	29	2	40
Lao PDR	Bolikhamxay	Bolikan, Viengthong	75	4	80
Lao PDR	Champassak	Bachiang, Kong, Pathoumphone	85	6	120
Lao PDR	Vientiane Capital	Park Nguem, Sangthong	95	4	71
Lao PDR	Xayyabouly	Kenthao, Paklay	74	4	80

[a]Percentage of the province population represented by the ethnic majority group. In Lao PDR, 2014 estimates calculated on the basis on Lao-Tai ethnolinguistic group (Ministry of Health, Lao People's Democratic Republic, 2015), in Cambodia based on ethnic minority headcount data reported from 2006 (Phath & Sovathana, 2012)

Table 2 Characteristics of auction products presented to farmers

Attribute	Product 1 (P1)	Product 2 (P2)	Product 3 (P3)
Variety	Unknown (KU50)	Elite (KU50)	Elite (KU50)
Susceptibility to CMD	Unknown	Low	Low
Stem source	Farmer stems	Farmer stems	Clean stems

Variety indicates the information presented to farmers, while in brackets is the real identity of the stem, in all cases the elite variety KU50

Vientiane, Lao PDR and in Phnom Penh, Cambodia immediately preceding auction preparations to ensure that the products did not appear old or dehydrated.

2.3 Auction implementation and data collection

A uniform protocol for auction implementation was employed across both countries. Auctions were held between November 10th, 2020, and April 5th, 2021, prior to and during the major cassava planting seasons (for precise dates see Appendix, Table 9). The length of the implementation period was due to extensive travel restrictions imposed during the SARS-CoV-2 pandemic.

Due to associated complications with planting material availability, we were not able to complete the sale to the highest bidder immediately following the auction. Instead, we informed participants prior to auction implementation that two 'winning' auctions would be randomly selected. In many auction experiments, researchers employ a multi-round approach, randomizing the 'winning' round and product, often including up to 10 rounds (e.g. Chern & Chang, 2012; Cherry et al., 2004; Dianat & Freer, 2021). In our adapted design, a single round was employed with 'winners' randomized to auction level. The approach of randomizing 'winner' to auction has been employed by other authors (e.g. Maredia et al., 2019). Thus, instead of combining the selection of the winning round in a multi-round auction – which is the most commonly used auction design - we assigned the selection of the winning auction to multi-auction selection. In Cambodia the planting window is more uniform, while in Lao PDR auctions proceeded from South to North, following the gradation in planting windows. In all cases more than 20 attendees arrived except in Sangthong district of Vientiane province where only 11 attendees arrived due to a conflicting village event.

All auctions were held in the morning, starting between 8:00–9:30 a.m. and finishing before noon to minimize variation, interference with farming responsibilities, and potential time of day effects (Morawetz et al., 2011). Auctions were held in accessible communal meeting locations (typically a village meeting hall, training center, school, or Buddhist temple), selected by village heads to reduce travel barriers to participation (Kaaria et al., 2016). Participants were numbered discreetly and physically distanced in the auction space to reduce possible collusion.

Neither endowments nor participation fees were employed to avoid house money / windfall effects and perceptions of experimenter demand on participants (Banerji et al., 2016; Cherry et al., 2005), with participants instead using their own money. This was deemed to be less of a barrier to participation than has been presented elsewhere (e.g., Waldman et al. (2014)) due to the relative low cost of a single bundle of cassava planting stems (Delaquis et al., 2018), equivalent in value approximately to a bowl of noodle soup in a local restaurant. Participants were served snacks and drinks, but not lunch, following local custom for official village meeting activities.

Prior to the explanation of auction rules and demonstration of products, a pre-auction survey was implemented for each participant in Lao and Khmer languages. A copy of the questionnaire (English translation) is provided in the article Supplementary Information. The survey contained six sections, covering farmer and site identification, farmer and household characteristics, group membership and social networks, variety use and cassava stem exchange behaviors, farmer perceptions and knowledge, and household income and assets. Participants were read an informed consent script and advised that they were free to refuse participation, to decline to answer specific questions, or to change their minds at any time.

Stem auctions were conducted in a single, live round using a full bidding approach, with all products displayed and bid on at the same time (Hoffman et al., 1993), a recommended approach in cases where similar products may be available in the market (Alfnes, 2009; Maredia et al., 2019). Previous studies have proposed multiple rounds of bidding to assess changes in bidding behavior with exposure to information (Waldman et al., 2014), or to evaluate changes across rounds (Corrigan et al., 2012). However, issues with bid affiliation in the presence of high bidders have led some authors to discourage repeated-trial approaches in multi-product auctions (Corrigan & Rousu, 2006; Loureiro et al., 2013). The honest bidding logic of a single round auction may also be more intuitive for inexperienced participants (Harrison et al., 2004). In pilot tests, participants in Lao PDR consistently expressed unfamiliarity with auctions, and confusion and suspicion about the purpose of multiple rounds, suggesting that they would be tempted to 'save their highest bid for last', despite explanations that this conferred no strategic advantage. To reduce tendencies towards non-dominant strategies, the strategy-proofness of the auction design was explained to participants, a procedure suggested to increase truthful bidding (Masuda et al., 2022).

Care was taken to assure participants that auction staff would assist everyone in privately recording bids to avoid marginalizing illiterate participants. We employed a standard script, but allowed for repetition of instructions, questions, and clarification (Mastenbroek et al., 2021). To facilitate

discussion of plant disease, participants were shown a printed photograph of CMD infected plants with characteristic mosaic leaf symptoms, as applied elsewhere (Mwiti et al., 2020).

Auctions were conducted in local languages by a team of two auctioneers and two assistants. To reduce the possibility of experimenter effect, the same two auctioneers conducted all auctions in each country, in most cases as a team, but occasionally individually as required by auction scheduling.

A practice auction round was conducted using two bars of hand soap with equivalent value but different packaging to familiarize the subjects with the auction process without providing leading influence on the value of the goods to be auctioned (Briz et al., 2017; Lusk & Shogren, 2007, p. 62). After the practice round, the results were posted and discussed with participants to encourage clarification of the process. Because no endowment was provided, the practice round was hypothetical with no purchase taking place, but clear explanation that the auction itself would be binding.

For each product, participants were instructed to provide the highest price they would pay for a single stem bundle (20 mature stems) of each of the three products. The 20-stem bundle is a standard size throughout the Greater Mekong Subregion of Southeast Asia (authors' own unpublished data), and represents enough to plant 0.2 ha, given the typical Southeast Asian planting density of 10,000 stem cuttings per hectare. The single bundle amount was selected due to farmers' familiarity with expressing costs per bundle, and with the affordability for participants, but this provided little insight into the other important consideration of number of bundles farmers required, and if this had any influence on their bidding strategy. After all the bids were recorded, the participants were therefore asked to state the number of bundles of each product they would have been willing to purchase at their given prices for each product. To avoid influencing the single bundle WTP, farmers were not informed that this question would be asked until all single bundle bids were already recorded.

Bids were displayed (referenced only by participant number) for all three products on a paper chart followed by a group discussion. A single round bidding structure was employed with all products introduced at once to avoid potential issues of price feedback / posting (Corrigan et al., 2012), while post-auction display allowed participants to verify the recording of their own bids, giving them confidence in the integrity of the second price. After the auctions were completed, the group discussed the results, clarifying any remaining issues as well as describing qualitative experiences with the methods including reasons for giving 0 bids.

2.4 Validation: stem sales

Two auctions were selected as the 'winners' from the total sample, from the villages Mitsamphan and Mun Hai Mueang in Attapeu province in Lao PDR. On April 7–8, 2021, the researchers visited both villages to meet again with the participants and to offer one bundle of P3 for sale to each auction winner. In addition, on April 9–10 a sale of 1541 CMD-free bundles of the cassava variety Rayong 72, also displaying reduced susceptibility to CMD (Malik et al., 2022), was conducted with the assistance of a nearby cassava processing factory and the Lao National Plant Protection Department to validate the mean price obtained through the auction process. The location of the validation exercise was prioritized in a village where traders had previously introduced planting materials from Vietnam which were inadvertently infected with CMD, creating a small disease hotspot. The process provided additional information on the ability to address small outbreaks after harvest in this commercial context, with farmers actively paying for stems and not relying on free materials from the government or aid programs.

2.5 Data analysis

Auction and survey data were processed and compiled using R 4.0.3 (R Core Team, 2020). Overall mean bids were compared using pairwise Wilcoxon signed-rank tests with Benjamini Hochberg correction for multiple testing. Empirical cumulative distributions were calculated and plotted using the function 'stat_ecdf' within the R package ggplot2 (Wickham, 2016). To generate correlation coefficients between bid values and bundle numbers requested, pairwise Spearman rank correlations were employed for their monotonicity and robustness to outliers using the R package 'corrplot' (Wei & Simko, 2021).

To evaluate the socioeconomic factors associated with farmers' WTP for planting material of different quality, determinants of WTP were modelled using a Seemingly Unrelated Regression Equations (SURE) model, a system of linear regressions with cross-equation error correlation accounting for possible correlations across bid equations for a given individual. SURE models have been used in auction experiments for the comparison of WTP across diverse products including land (Carlberg, 2002), computers (Ow & Wood, 2011), fish (Fluvià et al., 2012), fruit juices (Tóth et al., 2020), and sweetpotato varieties (Mwiti et al., 2020). The WTP model was specified in Stata statistical software (Release 16; StataCorp, 2019) using the following system of equations:

$$b_{i,j} = \alpha + \beta X_i + \varepsilon_{i,j}$$

for all i and j, where $b_{i,j}$ is the bid of Participant i for Product j ($j = 1, 2, 3$);α is constant, X is a matrix of farmer and farm production characteristics, hypothesized to correlate with decisions to purchase different planting materials, and β are coefficients to be estimated. The error terms $\varepsilon_{i,j}$ are assumed to be correlated for an individual, but uncorrelated across individuals. X includes controls for age, sex of the respondent, relationship to the household head, ethnicity,

education, household size, number of children in the household under five years, and the number of years of residency in the village. Socioeconomic status indicators and livelihood strategies were captured using indicator variables for whether households participated in agricultural wage employment, non-agricultural wage employment, non-agricultural self-employment, and other livelihoods. We controlled for the value of the total annual household income (in USD equivalent) from all income sources reported. Currency depreciations since this time, especially in Laos, should be considered when interpreting some of the results given the mix of export oriented, domestically oriented, and subsistence-oriented activities within household livelihood portfolios; nevertheless, all values from both countries were converted to USD equivalent.

We further controlled for a simple proxy of farmers' social capital, reported as an index ranging from 0–4 based on whether respondents were related to i) the village leader, ii) a cassava trader or a factory owner, iii) an agricultural officer/extension agent, and iv) a political appointee or a government official. We also included a control for whether the respondent or anyone in their household was a member of any group/organization focused on cassava, and whether they had previously received training on a related topic. Due to the importance of access to agricultural credit in purchasing inputs (Akter et al., 2017; Mishra et al., 2018), we employed an indicator variable for whether the respondent had access to formal or informal savings or credit schemes.

We also included variables describing agricultural production characteristics, including the number of years of experience growing cassava, the total land (in ha) managed for cultivation with any crops, the share of that land under cassava cultivation, the number of cassava varieties grown, and an indicator equal to one if the respondent had previously received any training related to cassava production and equal to zero if the respondent had not.

Farmers were asked to report on their experience of problems with cassava pests and diseases. Because of the small sample, confusion with distinguishing symptoms, and heterogeneity of issues reported by farmers, we used an indicator equal to one if no problems were reported with diseases and zero if they reported at least one.

3 Results

3.1 Household and farm characteristics

Participants' descriptive statistics at country level are presented in Table 3. Mean respondent ages (47 in Cambodia and 45 in Lao PDR) did not vary significantly across provinces. The average age of cassava farmers approximated overall farmer

Table 3 Description and summary characteristics of socioeconomic and demographic variables employed in the SURE model

		Cambodia (N = 321)				Lao PDR (N = 391)			
Variables	**Description**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
age	Respondent age in years	46.50	12.69	20	75	44.93	11.02	19	80
resp_fem	Respondent is female	0.533	0.500	0	1	0.432	0.496	0	1
resp_head	Respondent identifies as household head	0.517	0.500	0	1	0.537	0.499	0	1
n_yrs_edu	Number of years of education	4.341	3.346	0	16	5.518	3.310	0	15
eth_min	Respondent identifies as minority ethnic group	0.000	0.000	0	0	0.205	0.404	0	1
hh_size	Household members	4.931	1.607	2	12	5.514	2.048	2	15
n_child_5	Number of children in household < 5 years of age	0.508	0.676	0	3	0.591	0.945	0	9
n_yrs_village	Number of years residency in the current village	30.29	18.35	1	75	31.05	15.19	2	71
land_cult_ha	Total land cultivated by respondent (ha)	3.896	6.373	0.3	100	5.035	4.070	0.4	34
sh_land_cass	Share of cultivated land planted with cassava	0.851	0.256	0	1	0.518	0.252	0.02	1
n_yrs_cass	Number of years of experience growing cassava	9.145	6.384	0.2	40	5.404	4.140	1	43
n_soc_net	Social capital score (from 0 to 4)	0.283	0.528	0	3	1.491	0.885	0	4
gr_member	Dummy, member of group with cassava activities	0.349	0.477	0	1	0.159	0.366	0	1
train_cass	Dummy, had training on cassava cultivation	0.455	0.499	0	1	0.376	0.485	0	1
used_com	Dummy, has used a commercial stem source	0.296	0.457	0	1	0.182	0.386	0	1
inc_agr_w	Dummy, has agricultural wage employment	0.302	0.460	0	1	0.156	0.363	0	1
inc_non-ag	Dummy, has non-agricultural wage employment	0.143	0.351	0	1	0.269	0.444	0	1
inc_self	Dummy, non-agricultural self-employment	0.050	0.218	0	1	0.100	0.300	0	1
inc_other	Dummy, other source of income	0.143	0.351	0	1	0.171	0.377	0	1
tot_inc_000	Total annual household income (thousands)	4.148	4.302	0	25	4.245	4.074	0	25
credit_ins	Dummy, has access to credit and saving schemes	0.100	0.300	0	1	0.404	0.491	0	1
N_var	Number of cassava varieties currently grown	1.483	0.676	1	4	1.067	0.288	1	3

Currency is expressed in USD equivalent

ages reported in the Greater Mekong Subregion (Rigg et al., 2020). However, average residence time in respondents' current village was lower in Cambodia (17 – 37 years provincial means) compared to Lao PDR (23 to 43-year provincial means), likely reflective of significant urban–rural and rural-rural internal migration patterns in Cambodia (Diepart & Ngin, 2020; Joshi, 2020). Female respondents accounted for 53% of the sample in Cambodia, and 43% in Lao PDR.

In Cambodia, all participants identified themselves as Khmer, while one in five respondents in Lao PDR self-identified as an ethnic minority, varying from 70% of respondents in Attapeu province to none in Vientiane and Xayyabouly. Social capital scores were higher in Lao PDR, perhaps due to generally lower population and village sizes and higher proportion of ethnic minority groups, which may have tighter networks (Winkels, 2012). Education was similarly low across provinces surveyed in both countries, ranging from 4.05 - 6.6 years of education in Cambodian provinces, and 3.8 - 5.9 years in Lao provinces.

Cambodian farm sizes ranged from 3.1 ha in Banteay Meanchey to 4.4 ha in Battambang, but with a high share (85%) of farm area dedicated to cassava. This area dedication is indicative of the much higher national cassava production area in Cambodia, where the crop is only surpassed in area dedication by rice. Household farm sizes in Lao PDR were on average 1.3 ha larger, and ranged from 4.4 ha in Vientiane province to 6.8 ha in Attapeu, with a mean half of farm area dedicated to cassava production across provinces.

The importance of cassava production in Cambodia was apparent throughout the survey responses, with Cambodian farmers indicating nearly twice as many years of cultivation experience, more than double the frequency of membership in a group or association related to its production, and greater participation in cultivation training than their Lao counterparts, although in both countries variation by province was notable in all three variables. The importance was also reflected in the income streams reported, with Cambodian farmers relying more heavily on agricultural incomes and wage employment, while Lao PDR households indicated greater prevalence of off-farm income sources. This role of off-farm incomes in Lao may be related to the strong trend of labor migration to neighboring Thailand in Lao families as noted by other authors (Manivong et al., 2014).

3.2 Cassava varieties and stem exchange

The average number of cassava varieties reported by households averaged < 2 in all provinces of both countries, with Cambodian farmers reporting slightly more diversity. Perceptions of yield losses due to pest and disease were comparable across Cambodian provinces (from 33% in Battambang to 43% in Tboung Khmum) and in Lao provinces (from 20% in Vientiane to 34% in Attapeu), despite the much more widespread nature of the CMD epidemic throughout Cambodia.

In Lao PDR 28% of farmers reported using stems from their own supply from the previous year, compared to 62% in Cambodia. For off-farm transactions, stem sources accessed varied (Table 4). Total off-farm acquisitions in the previous year were relatively high in both countries considering cassava's status as a VPC allowing self-sufficiency in stem supply. In both cases over half of acquisitions originated from other farmers within the community. However, in Lao PDR farmers outside the community and factories both played important roles in stem supply. Conversely, Cambodian farmers relied much more strongly on traders, with an absence of direct factory involvement and a role played by root collection points and NGOs.

Accessing commercial stem sources was more common in Cambodia, although average prices paid for stems from those sources were similar (Table 5). Lao PDR farmers reported paying a 20% higher price for stems from farmer sources compared to their Cambodian counterparts. Notably, in both countries when stems were purchased from commercial sources, farmers reported having paid higher prices than when bought from other farmers. The implication of the complete absence of seed company involvement in cassava stem production and limited supply from government sources in the GMS (Delaquis, 2023) is that the ultimate source of the commercial stems in this case is primarily from farmers' fields and often sold by actors connected to the cassava root or cassava chip value chains.

Table 4 Share of total external stem source accesses in the preceding season (omitting farmers' own saved stems) in Cambodia (321 respondents, 242 unique transactions) and Lao PDR (391 respondents, 288 unique transactions)

Source category	Source type	Cambodia (%)	Lao PDR (%)
Farmer	Farmer in community	56.2	54.5
	Farmer outside community	12.0	24.3
Commercial	Factory	0.0	12.2
	Trader	24.4	7.6
	Collection point	3.3	0.3
Various	NGO	3.7	0.0
	Government	0.0	0.7
	Cooperative	0.4	0.3

Table 5 Number of exchanges reported and prices per bundle recalled by participants in Cambodia (N = 150) and Lao PDR (N = 368) from the previous season, calculated for two source categories from Table 4: 'farmer' (including both farmers inside and outside the community, both known and unknown to the purchaser) and 'commercial' (including stems obtained from traders, factory, or collection points), while the remainder included free provisions from NGO, government, and cooperative sources

	All sources	Farmer sources	Commercial sources
Total purchases	530	74%	24%
Price	1.12 (±0.76)	1.05 (±0.77)	1.31 (±0.71)
Cambodia	242	68%	28%
Price	1.00 (±0.55)	0.87 (±0.48)	1.30 (±0.59)
Lao PDR	288	79%	20%
Price	1.20 (±0.88)	1.17 (±0.90)	1.33 (±0.81)

3.3 Auction bidding

At a national level, bid prices were significantly higher ($p < 0.0001$) for P2 and P3 in both Cambodia and Lao PDR, indicating bidders placed a premium on the improved stem products (Fig. 2). Bids for P3 were significantly higher than for P2, showing that in addition to valuing the elite varieties, farmers also placed a premium on tested stems. Bids varied by province, rather than by district or village, suggesting that provincial scale characteristics influencing availability and transport costs may play important roles in setting local prices. While bid prices per bundle of 20 stems for P1 were similar between countries, P2 and P3 both obtained higher average bids in Lao PDR than in Cambodia.

Bids of 0 were more common in Lao PDR, with 119, 35, and 1 participant bidding 0 for Products 1, 2, and 3, respectively. By contrast, in Cambodia only a single participant bid 0, and only for P1. Despite this, auctions in Lao PDR also commanded higher mean average bids for Products 2 and 3 (and P1 if 0 s had been excluded). One potential explanation for this trend is the higher level of commercialization in the stem exchange network in Cambodia resulting in farmers more readily conceptualizing stems as a market product, while increased availability of stems also resulted in higher supply and lower overall prices. Provincial variations were notable in bid density distributions observed from both countries (Fig. 3). In general provinces with large and established production areas like Battambang, Banteay Meanchey, and Bolikhamxay tended to display smaller difference between product means, while newer production areas like Attapeu, Champassak and Kratie displayed larger differences. Outliers on the right side of the graph, representing high bids, were notably much higher in Lao PDR than in Cambodia.

When asked in the post-auction group discussions to explain the reason for bids of 0, individuals gave a range of reasons broadly defined by four main categories: the (lack of) credibility of the information presented, lack of demand

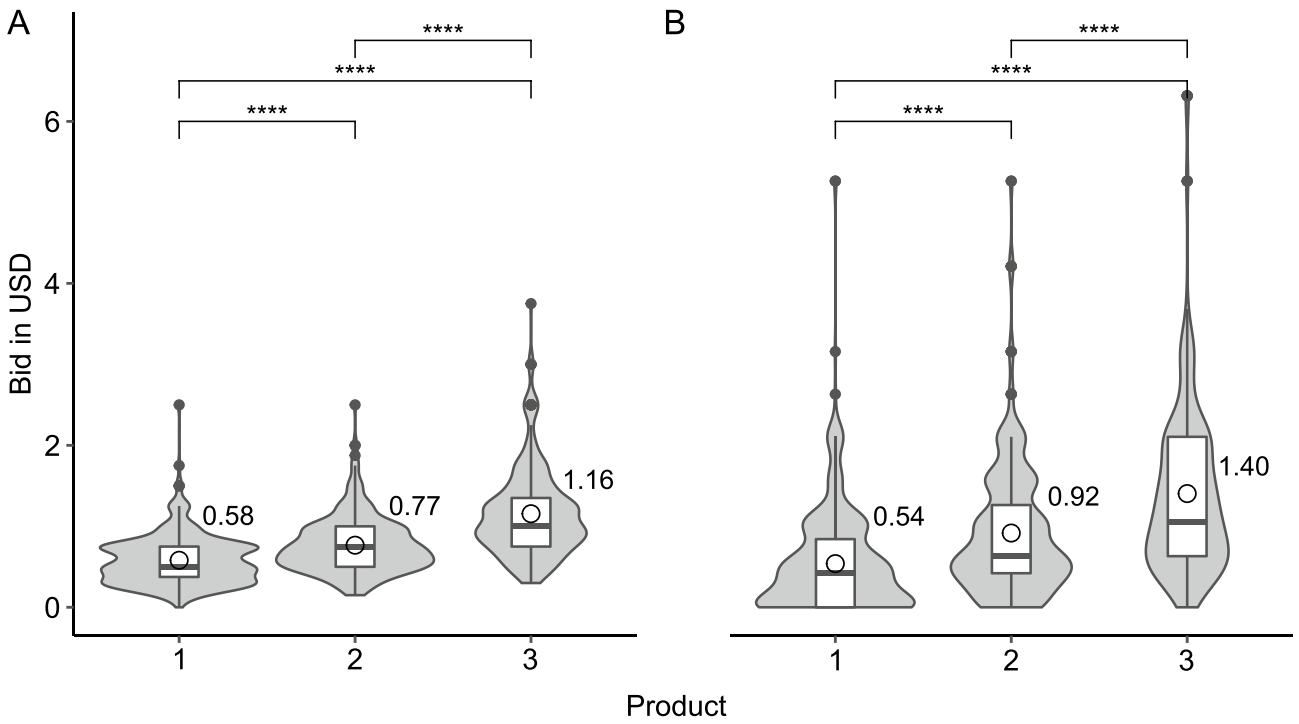

Fig. 2 Pairwise Wilcoxon signed-rank tests with Benjamini Hochberg correction for multiple testing between bids for auctioned products in **A** Cambodia and **B** Lao PDR. Violin boxplots denote the underlying data distributions and interquartile ranges, while hollow circles indicate the labeled mean bid value for each product in USD equivalent, with **** $p < 0.0001$ for all comparisons

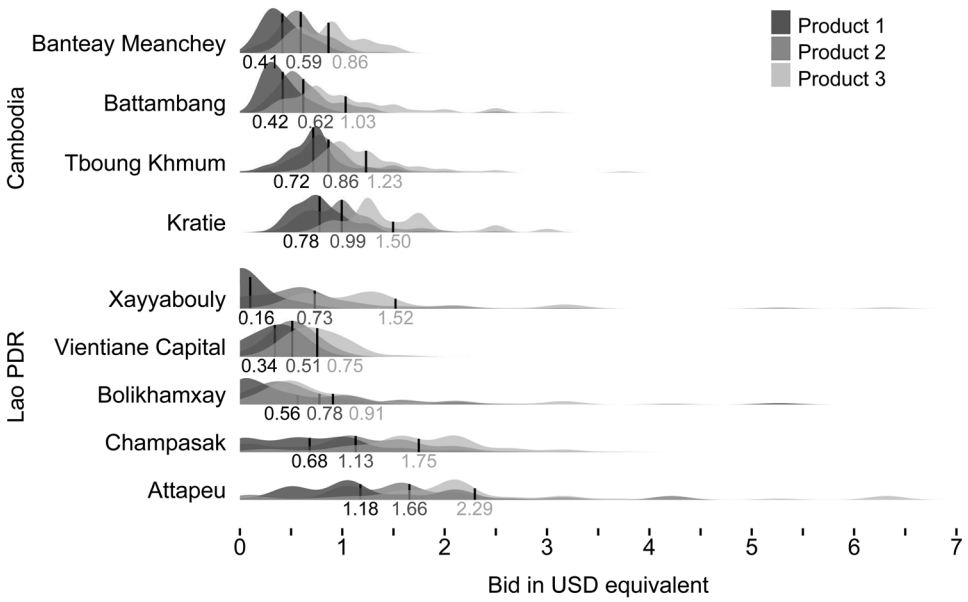

Fig. 3 Experimental auction derived bid distributions by product and province in Cambodia and Lao PDR. Vertical lines and shade-coded values indicate bid means of province by product distributions

for the materials offered, the appearance of the planting materials, and the availability or prioritization of money (Table 6). Responses did not display any characteristic geographic or demographic groupings (data not shown).

Empirical cumulative distribution functions for each country are presented in Fig. 4, alongside survey-determined mean prices paid for farmer and commercial stem categories as presented in Table 5. The larger steps in each estimated distribution curve correspond largely to convenient local currency denominations in each country. Lao PDR exhibits curves beginning earlier and with shallower slopes for P2 and P3, with a greater fraction of participants willing to pay values on the higher end of the price distribution. For P3, while only a tenth of Cambodian participants placed bids higher than 2 USD, over a quarter of Lao participants did so. The gap between products was also significantly larger in Lao PDR due to very low values for P1, although respondents in both countries placed very low bids for farmer stems compared to the threshold established by farmer stem prices in the previous season obtained from survey responses.

Approximately 40% of both Cambodian and Lao respondents bid higher for P3 than the mean price for commercial stems reported in the surveys. For P2, approximately a quarter of Lao respondents still bid above the same threshold, compared to only 12% in Cambodia. This indicates significant interest in the population to purchase the clean stem product, especially when considering that VPC seed is in most cases not purchased every year. These findings suggest strong market demand for improved stem products in Lao PDR. While a smaller share of Cambodian farmers was willing to pay high prices, demand was nevertheless significant, especially below the 2 USD threshold. The high bids in Lao PDR may be indicative of several contributing factors, including lower supply and higher demand for improved stem products, or lack of exposure to established stem market prices due to inexperience with stem purchasing.

Table 6 Illustrative example comments from group discussion participants bidding zero for one or more of the auctioned products

Category	Generic comment
Credibility	I want to see proof of varietal performance before buying
	I don't believe researchers' claims – we farmers have more experience
Demand	I have enough stems from my own supply
	I already made purchases for this season
	I just purchased last year – won't purchase again for several seasons
	I don't have any more land to plant
	Simply not interested in buying
Appearance	We have seen this type of stem before (not novel)
	Stems look shorter than those from our community
Money	Prefer to spend my money on something else
	I can get cassava stems for free

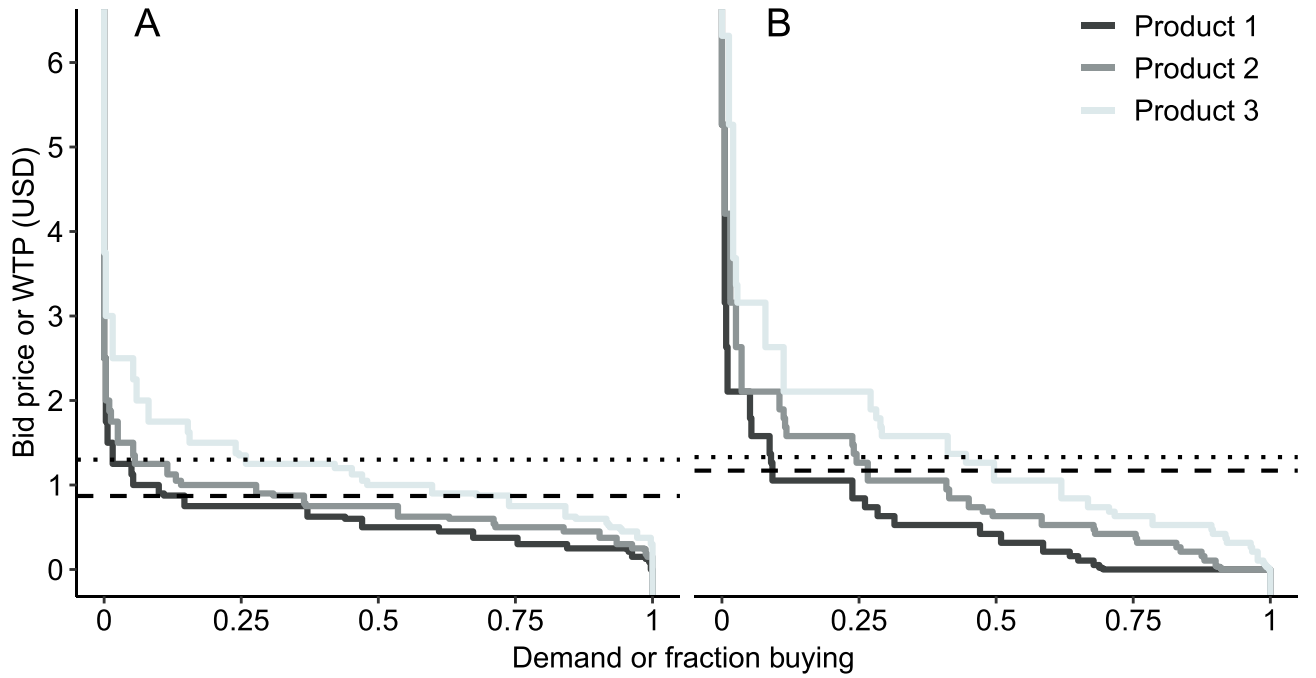

Fig. 4 Empirical cumulative distribution plot for stem demand for the three tested products in **A** Cambodia and **B** Lao PDR. The dotted and dashed lines indicate reported average prices paid for stems from commercial and farmer sources, respectively, in each country

3.4 Determinants of willingness to pay for cassava stems

The results of the WTP SURE models for Cambodia and Lao PDR are presented in Tables 7 and 8, respectively. Province had very strong effects in both countries, while the influence of other factors varied. As described above, no self-identified ethnic minority farmers took part in the auctions in Cambodia, precluding us from analyzing how WTP may differ depending on other constructions of ethnic identity in Cambodia. In Cambodia, although the bids of female respondents were lower than the bids of male respondents, the difference was not statistically significant. In Lao PDR, both sex and ethnicity had significant effects on WTP, with female participants indicating lower WTP than males, and self-identified ethnic minorities indicating higher WTP values than majority groups.

Controlling for farmer characteristics, WTP values were consistently higher in both countries for P2 and P3 successively. Across provinces, there was more heterogeneity in bidding with respect to P3, the most differentiated product representing the 'highest quality' stems. Variation among provinces also appeared to show regionalized trends, with the Cambodian reference province of Tboung Khmum showing no significant difference for P1 with neighboring Kratie province. Eastern Cambodian provinces had significantly higher WTP values across products than Battambang and Banteay Meanchey in the West (except for P3 in Battambang). Likewise in Lao PDR, the reference province of Attapeu showed significant differences with the remaining provinces for all comparisons except for P1 and P2 in neighboring Champassak. The WTP prices in these two Southern provinces were significantly higher than any of the provinces found in the center and north.

3.5 Number of bundles requested

The results of the post-bid solicitation for number of bundles participants would purchase (Fig. 5) indicated that Cambodian respondents included a small proportion of 'test purchases' (1 – 50 bundles). These numbers are fairly trivial (enough to plant < 0.5 ha) compared to the planted cassava areas reported in the survey, suggesting that farmers were interested in acquiring small numbers for testing or evaluation purposes. This may again reflect the conception of cassava stems as a market commodity, with units of 50 bundles being a typical familiar bulk order quantity. Cambodian respondents frequently requested higher numbers of bundles (up to 2000, enough to plant > 15 ha). Lao PDR respondents more frequently requested 0 bundles for P1 and P2, and in general requested relatively small numbers of bundles, with most non-zero responses falling between 1 and 50 bundles. Only for P3 a similar trend appeared of bulk purchases in increments of 50.

To identify the strength of correlations between individuals' bids for the three products and their later reported bundle numbers, pairwise correlations were applied to the rank-transformed data (Fig. 6). Bids were highly positively

Table 7 Determinants of willingness to pay for cassava for planting material products in Cambodia

Variables	Product					
	1	SE	2	SE	3	SE
age	0.00238*	0.00139	0.00212	0.00165	0.000224	0.00256
resp_fem	-0.0157	0.0446	-0.0423	0.0528	-0.0633	0.0822
resp_head	-0.0200	0.0435	0.00979	0.0515	-0.00947	0.0803
n_yrs_edu	-0.000997	0.00491	0.00393	0.00581	0.0216**	0.00905
eth_min	-		-		-	
hh_size	-0.0156*	0.00928	-0.0188*	0.011	-0.00718	0.0171
n_child_5	0.0318	0.0227	0.0106	0.0268	0.0317	0.0418
n_yrs_village	-0.000515	0.00113	0.000179	0.00134	0.00506**	0.00208
gr_member	-0.0352	0.0346	0.0130	0.041	0.0776	0.0638
n_soc_net	0.000537	0.0289	0.0454	0.0342	0.00500	0.0533
inc_agr_w	0.0246	0.0329	-0.0154	0.0389	-0.0214	0.0606
inc_non-ag	-0.0177	0.0427	-0.0656	0.0506	-0.0524	0.0788
inc_non-ag-self	-0.0451	0.0673	-0.0737	0.0797	0.136	0.124
inc_other	-0.0786*	0.0434	-0.0541	0.0514	0.00763	0.08
tot_inc_000	0.000779	0.00411	-0.00141	0.00487	0.00714	0.00759
credit_ins	0.0960**	0.0475	0.00507	0.0562	0.0128	0.0876
n_yrs_cass	-0.00291	0.00266	-0.00311	0.00315	0.00254	0.00491
train_cass	0.00974	0.0332	0.0105	0.0393	0.0395	0.0612
used_com	0.0328	0.0327	-0.0371	0.0387	-0.0560	0.0603
land_cult_ha	-0.00130	0.00264	-0.000814	0.00313	-0.00617	0.00487
sh_land_cass	-0.0262	0.0616	-0.0598	0.0729	-0.315***	0.114
N_var	0.00502	0.0219	0.0108	0.026	0.0702*	0.0405
Prov: Tboung Khmum	-		-		-	
Prov: Banteay Meanchey	-0.333***	0.0481	-0.286***	0.057	-0.229***	0.0887
Prov: Battambang	-0.325***	0.0497	-0.254***	0.0588	-0.00523	0.0916
Prov: Kratie	0.0341	0.0496	0.133**	0.0587	0.451***	0.0914
	-		-		-	
Constant	0.767***	0.116	0.940***	0.138	1.013***	0.215
R-squared	0.340		0.275		0.280	

SE Standard Error

*p < 0.1; **p < 0.05; ***p < 0.01

correlated with each other in both countries: bid prices were consistently high or low for an individual across products. Bundle numbers were weakly affiliated with each other in Cambodia but were highly positively affiliated in Lao PDR. While Cambodian individuals varied the relative numbers of bundles for each product, Lao participants requested more constant numbers of bundles across all products. While in Cambodia the numbers requested for P1 and P2 were positively correlated the association weakened and even reversed for the other products, suggesting an attempted compromise between price and quantity. The lack of association in Lao PDR may suggest that numbers were based on current need rather than seeking to maximize economic benefit.

3.6 Auction follow up sales

With the help of district officials, the two villages in Attapeu province of Lao PDR were visited for follow up stem sales. To test the second price point, we first attempted to contact the winners, and then offered stems for sale to the larger group at the mean district bid price. In addition, a larger open sale event was organized at district level.

In Mitsamphan village, ten attendees returned to the follow-up sale. The auction winner was not able to attend due to migration for labor, but assured on the telephone that they would have purchased at the second price point of 4.2 USD for a single bundle. The attending group members were unanimous that the winning bid was too high, stating that 'the winner did not have enough experience with cassava cultivation to understand normal stem prices.' However, the mean bid of the district of 1.3 USD, resulting from the auctions, was seen by the group as a fair price. The group estimated that the average market price that season had fluctuated between 1.2 and 1.5 USD. The 150 bundles available were purchased by five people, each purchasing from 10 to 50 bundles for 1.3 USD per bundle.

In Mun Hai Mueang, twelve participants attended the follow-up sale. We were informed that the winner had

Table 8 Determinants of willingness to pay for cassava for planting material products in Lao PDR

Variable	Product					
	1	SE	2	SE	3	SE
age	-0.00319	0.00324	-0.00338	0.00388	-0.00107	0.00487
resp_fem	-0.154	0.121	-0.340**	0.145	-0.444**	0.182
resp_head	-0.163	0.12	-0.255*	0.144	-0.288	0.180
n_yrs_edu	-0.0165	0.0101	-0.0130	0.0121	-0.0193	0.0152
eth_min	0.350***	0.0898	0.454***	0.108	0.323**	0.135
hh_size	0.0188	0.0171	0.0386*	0.0205	0.0130	0.0257
n_child_5	0.0335	0.0424	0.0658	0.0508	0.0309	0.0638
n_yrs_village	0.00336	0.00234	0.00201	0.0028	-0.00145	0.00352
gr_member	0.00866	0.0969	0.0289	0.116	-0.224	0.146
n_soc_net	0.0183	(0.0379	0.0103	0.0454	0.0229	0.057
inc_agr_w	0.0245	0.0838	0.0168	0.100	-0.131	0.126
inc_non-ag	0.127	0.0769	0.198**	0.0922	-0.0250	0.116
inc_non-ag-self	-0.0942	0.105	-0.182	0.126	-0.340**	0.158
inc_other	0.0284	0.080	0.0637	0.0959	0.0190	0.120
tot_inc_000	-0.0114	0.00832	-0.0203**	0.00997	-0.00963	0.0125
credit_ins	-0.118	0.0726	-0.0331	0.087	-0.0335	0.109
n_yrs_cass	-0.00729	0.00796	-0.0258***	0.00954	-0.0377***	0.012
train_cass	0.175**	0.0821	0.132	0.0984	0.00761	0.123
used_com	-0.0844	0.0845	-0.0628	0.101	-0.0787	0.127
land_cult_ha	0.00952	0.00837	0.0127	0.0100	0.0264**	0.0126
sh_land_cass	-0.00245	0.127	-0.150	0.152	-0.375**	0.190
N_var	-0.211*	0.117	-0.0405	0.141	-0.00932	0.176
Prov: Attapeu	-		-		-	
Prov: Bolikhamxay	-0.520***	0.145	-0.498***	0.174	-0.850***	0.218
Prov: Champasak	-0.380***	0.136	-0.139	0.163	-0.0627	0.204
Prov: Vientiane	-0.705***	0.168	-0.725***	0.201	-0.913***	0.252
Prov: Xayyabouly	-0.688***	0.162	-0.295	0.194	-0.182	0.243
Constant	1.329***	0.326	1.550***	0.391	2.594***	0.490
R-squared	0.278		0.285		0.308	

SE Standard Error

*p < 0.1; ** p < 0.05; *** p < 0.01

traveled away from the village and were unsuccessful in reaching them by telephone after repeated attempts. The group stated that the second price, and the district mean of 1.3 USD, were both too high. The participants did not wish to purchase, stating 'we still have stems available', 'those stems look short compared to ours', and 'we prefer to wait until we see proof what the yield will be'. The 75 bundles were only sold once the price was lowered to 1 USD, by seven buyers, each purchasing between 2 and 20 bundles.

The district level sale included 1541 bundles. The activity attracted 32 farmers from the CMD affected districts, who registered and offered cash for all the available bundles at the 1.3 USD district mean price point. The distribution of the numbers of bundles purchased closely mirrored the pattern observed in the auction elicitation: the large majority (23) of participants purchased ≤ 50 bundles, while 8 purchased 100 – 150 bundles, and a single buyer purchased 250 bundles.

4 Discussion

4.1 Stem attributes, motivations, and experience with stem purchase

The finding of a price premium attached to P2 and P3 in the auction suggests demand for elite varieties is high in both Cambodia and Lao PDR, even when disease issues were not yet identified as a dominant yield-limiting issue. The WTP for a bundle of clean stems of the elite variety was in both countries significantly higher than the WTP for a bundle of the stems of the same variety from a farmer source, indicating that the potential presence of yield depressing diseases motivates farmers to assign a higher value to tested stems.

While many purchasers did seek relatively small numbers of bundles (< 50), a smaller but persistent proportion sought large numbers sufficient for whole-field plantings (100 – 1000+). This distribution was echoed in the

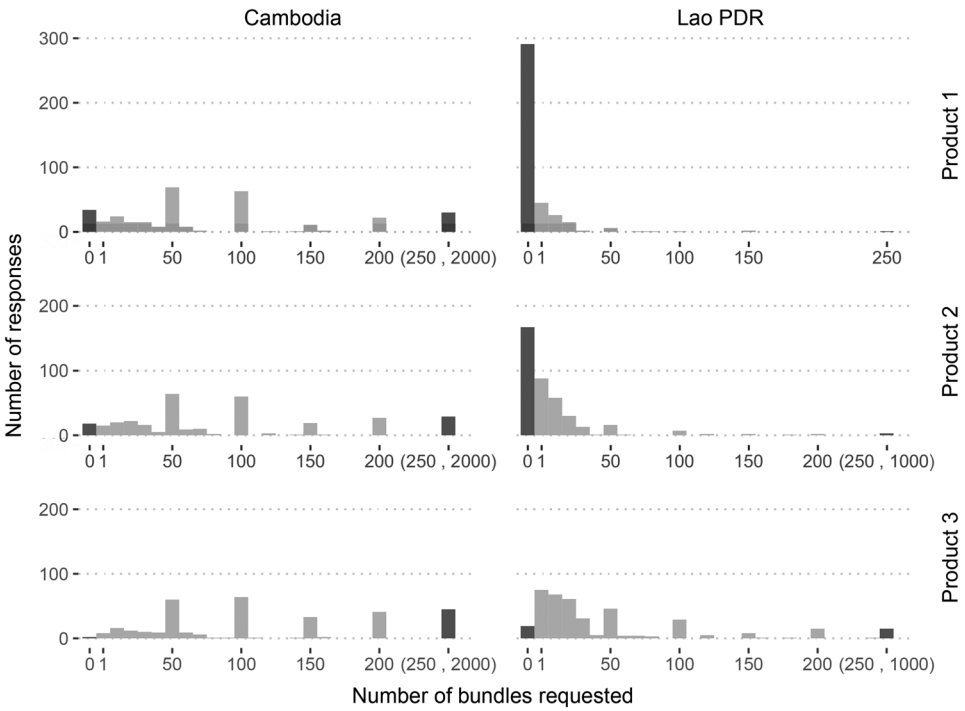

Fig. 5 Post-bid numbers of bundles desired for each country by product combination. Dark grey bars on the left and right of each panel denote counts of 0 values and binned count of values above 250, with range provided in brackets

results of the open district stem sale. The lack of significant rank correlations between bids and bundle numbers among participants also provides some confidence that participants did indeed follow the instructions to bid with only the value of a single bundle in mind, despite their actual needs. The bulkiness and divisible nature of cassava stems, typical of VPCs, presented a challenge in the study. While it is common practice for farmers to discuss prices of stems in terms of a single bundle of stems and the auction displayed single bundles as well, they then must relate this to overall household budget constraints and develop a seasonal purchase strategy. Setting the auction unit as a larger number (e.g., 100 bundles) would have risked exclusion of those with smaller areas of land, less available cash or credit, or seeking a small amount for testing purposes. This issue is present across a range of auction studies for crop seeds, but it has so far received little attention.

4.2 Country and socio-economic determinants

Non-zero bids for all products were higher in Lao PDR auctions than in Cambodian ones. Nevertheless, cassava stem purchase experience indicated that Cambodian participants paid less for stems from both farmer and commercial sources than their Lao PDR counterparts. This may reflect the larger production area of cassava in Cambodia resulting in a higher availability of farmer stems compared to Lao PDR's smaller national area and half the number of years of experience growing cassava on average. The fact that Cambodian farmers came up with fewer zero bids suggests a higher level of commercialization of the stem sourcing practices. Lao farmers in this study more frequently accessed stems from farmers outside the community and from factory agents. Despite slight differences in the stem sourcing practices of farmers in the two countries, we found no significant effect of previous use of a commercial source on WTP for any of the three offered products.

In addition to country, provincial variation of WTPs was significant. We assume that the provincial effect on WTP is influenced by features like accessibility to markets (in this case cassava processing and export facilities, including starch factories and chip collection points), concentration of cassava cultivation (and thereby transport network logistics and associated costs), and the dynamics of local government and private sector actors engaging in support in stem access. In this study, we did not seek to disaggregate the influences of these features related to the situatedness of the study communities in the center or periphery of the major cassava production areas. We do however note these features have a strong association with the presence of ethnic minority groups in our study villages. In Lao PDR WTP was higher for ethnic minority participants – a finding which may be influenced by more peripheral positioning of their villages, thereby reducing the availability of cassava planting materials. Cultural experience with the use of cassava for direct human consumption and social structure of ethnic minority communities in both Cambodia (Baradat, 1941; Matras & Martin, 1972) and Lao PDR (Halpern, 1961; Vidal & Wall, 1968) may play an undetermined role in local valuing of cassava planting materials. Social structure and moral norms also likely play

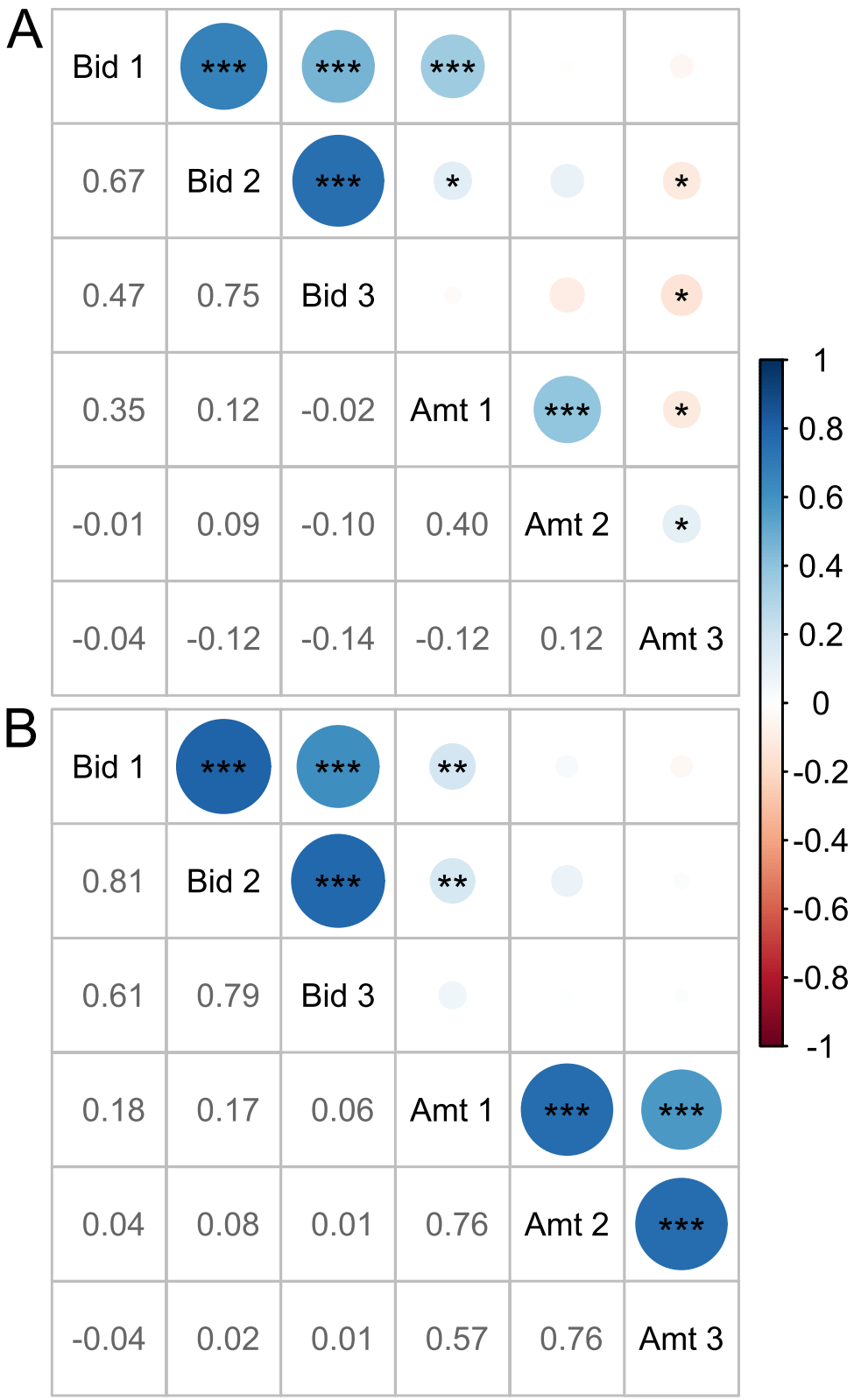

Fig. 6 Spearman rank correlations with Benjamini-Hochberg adjustment for multiple testing of product bids and bundle numbers (Amt) from auction participants in **A** Cambodia and **B** Lao PDR. Spearman rank correlation coefficients are indicated by the color scale and lower triangle coefficients; circles and asterisks indicate correlation significance levels (p = ***0.001, **0.01, and *0.05)

roles in stem trading activities that were not captured by our survey structure (Beban & Gironde, 2023; To et al., 2016).

Women in Lao PDR exhibited lower WTP than men for both improved products offered. However, a larger household size had a significant negative effect on WTP for P1 and P2. With greater responsibilities in caregiving for children and elderly, and more responsibility for household chores (Hoang et al., 2015; Teerawichitchainan et al., 2019), women may differently perceive the risks and benefits associated with spending household resources on stems, and there is some evidence that in the context of GMS cassava production women are more reliant on social networks for access to stems, while men access commercial sources (Kawarazuka, 2017). In Cambodia, we identified fewer socioeconomic variables affecting WTP. For elite tested stems these included higher WTP with increased education and years living in their village, and lower WTP with increasing share of total land planted to cassava; which may reflect greater confidence in their management of their own established stem supply.

4.3 Experimental auctions for vegetatively propagated seed

We assessed demand prior to and during the cassava planting season, with the recognition that cassava stems have low viability after storage > 3 months in the GMS environment (Delaquis et al., 2018; Sinthuprama & Tiraporn, 1986). The perishability of cassava stems means that, from a self-use perspective, it effectively loses its value once the planting period is over (or the farmer has already met their stem needs for the year). This may help to explain the large number of 0 bids for the farmer stem product in Lao PDR but not in Cambodia, the latter of which has a larger cassava sector. Our findings of lower number of zero-bids in the Cambodian auctions aligns with the notion that farmers in this country have a more developed conception of stems as a product with commercial resale value, in addition to self-use.

Our results contribute to a growing number of studies applying auction formats for valuation of VPC seed, and find that geography, gender, and ethnicity importantly influenced WTP values. The WTP values we found match earlier reported findings on prices paid for casava stems and the variation thereof. Soukkhamthat and Wong (2016) found cassava stem costs to be a primary constraint in production economics in Lao PDR, with lower prices (0.25 USD) in the established production area of Vientiane, and higher prices (2.5 USD) in the southern province of Savannakhet. Overall, the participant information on stem-sourcing and observed bids reflect that cassava stems are commonly purchased by farmers in Cambodia and are viewed as a commercial product. In Lao PDR there were a substantial number of farmers offering a 0 bid for farmer stems. Delaquis et al. (2018) described the level of local production intensity shaping stem exchange behaviors, and it is possible that the 0 bids reported in Lao PDR reflect factors associated with lower production intensity, limited stem markets, and common acquisition through non-financial transactions within local networks.

Two biases observed in auction studies did not seem to play a role in our study. Misconception of the participants on the purpose of the auction can explain the frequently observed gap between WTP and the related concept of willingness to accept. This may lead to the tendency for participants unfamiliar with auctions to bid strategically, even when this is explained to have a low chance of success (Plott & Zeiler, 2005). The bids in our study did not indicate significant misconception, with bid values following the expected product order without bid inversion, and comparing favorably with average stem prices reported from previous years, and in similar contexts (Delaquis et al., 2018). Another potential bias of auctions is 'anchoring', detectable when practice bids and real bids are found to be correlated (Corrigan et al., 2014). Analysis of practice round and bid data in our data from Lao PDR (not shown) found high degrees of correlation within practice round bids (using soap) and within the product bids (stems), but not between each other, suggesting that product valuations were not strongly anchored.

5 Conclusions

Our results contribute to understanding farmer demand for VPC seed and highlight relevant factors for farmer valuation of cassava stem traits within a range of commercial contexts in the GMS cassava sector. Auctions provided a method for relatively efficient gathering of revealed preference data in situ, and yielded realistic revealed WTP estimates for cassava stem products across a range of local contexts, echoing the findings of similar studies in other countries (Berry et al., 2020; Maredia et al., 2019; Mastenbroek et al., 2021; Mwiti et al., 2020). The presence of a well-developed commercial value of stems may be crucial in this respect. As expected, 'winning' bids obtained through our auction design represented high outliers, but average bid prices obtained were deemed acceptable when products were offered to farmers at an unstructured open sale in one participating district of Lao PDR, and compared favorably with reported stem purchase prices from the previous year.

In contrasting results from Cambodia and Lao PDR, farmers expressed consistent and significant WTP premiums for both the disease-resistant variety and clean stem products compared to farmer stems, indicating a relatively strong demand for improved varieties and clean stems. The findings support the potential viability of commercial systems for vegetatively propagated cassava clean stems (and eventually CMD resistant) production and dissemination models. Whether the observed WTP premiums for both the elite variety and tested stems are sufficient to counter the additional costs of stem production, or whether subsidy is required, remains to be seen. Nevertheless, improved stems have an important role in addressing the spread of both CMD

and other current and future cassava diseases. Our results suggest that variety turnover is not hindered in the GMS context by a low (or lack of) WTP for clean planting materials and new varieties. The strong controlling effects of province in our WTP model suggest an influence of larger scale market forces on local prices, possibly mediated through the presence of long-distance networks of cassava planting stem supply and exchange facilitated by intermediate traders (Delaquis et al., 2018). Provincial variability should thus be included in planning strategies for stem production and dissemination.

Whilst the study demonstrates the high willingness of households to enter the stem market at different prices, additional approaches are needed for nuanced price discovery in different contexts, to identify the total quantities demanded at different price points, and to design appropriate dissemination strategies.

Policymakers and social programs seeking to ensure that marginalized groups benefit from ongoing cassava production increases should focus on the identification of barriers to both quality and accessibility of stems. In Lao PDR, our findings call for further research on the underpinning social and economic influences accounting for the higher WTP observed among ethnic minority groups. In Cambodia, further research should identify socioeconomic or cultural indicators applicable where ethnicity has shown to be inadequate. Our findings provide guidance for initiatives aiming to develop and scale cassava stem products in the Greater Mekong subregion, and for the control of stem-borne diseases like CMD.

Appendix

Table 9 List of experimental auction villages, dates conducted and number of participants (n)

Country	Province	District	Village	Date	n
Cambodia	Banteay Meanchey	Preah Net Preah	Popel	2022-01-10	20
Cambodia	Banteay Meanchey	Preah Net Preah	Chroab Chas	2022-01-11	20
Cambodia	Banteay Meanchey	Svay Chek	Doun Nouy	2022-01-12	20
Cambodia	Banteay Meanchey	Svay Chek	Khvav Lek	2022-01-13	20
Cambodia	Battambang	Banan	Thngor	2022-01-15	21
Cambodia	Battambang	Ratanak Mondul	Badak Cheung	2022-01-18	20
Cambodia	Battambang	Rukhak Kiri	Paen	2022-01-16	20
Cambodia	Battambang	Rukhak Kiri	Prey Ampoan	2022-01-17	20
Cambodia	Tboung Khmum	Dambae	Kouk Srok	2021-12-13	20
Cambodia	Tboung Khmum	Dambae	Srae Veng	2021-12-15	20
Cambodia	Tboung Khmum	Tboung Khmum	Smaonh	2021-12-14	20
Cambodia	Tboung Khmum	Memot	Lour	2021-12-16	20
Cambodia	Kratie	Chhloung	Pralay Triek	2021-12-27	20
Cambodia	Kratie	Chhloung	Danghit	2021-12-28	20
Cambodia	Kratie	Chet Borei	Trapeang Triang	2021-12-29	20
Cambodia	Kratie	Chet Borei	Okouki	2021-12-30	20
Lao PDR	Attapeu	Samakhixay	Yai Meun Hua Meung	2020-11-11	20
Lao PDR	Attapeu	Sanamxay	Mitsampan	2020-11-10	20
Lao PDR	Bolikhamxay	Bolikan	Hadpho	2021-01-30	20
Lao PDR	Bolikhamxay	Bolikan	Phonthong	2021-01-29	20
Lao PDR	Bolikhamxay	Viengthong	Namkang	2021-01-28	20
Lao PDR	Bolikhamxay	Viengthong	Vanghin	2021-01-27	20
Lao PDR	Champassak	Bachiang	Kuangsi	2020-11-13	20
Lao PDR	Champassak	Bachiang	Ladbok	2020-11-12	20
Lao PDR	Champassak	Kong	Nafung	2020-11-17	20
Lao PDR	Champassak	Kong	Nasanphan	2020-11-18	20
Lao PDR	Champassak	Pathoumphone	Sanod	2020-11-15	20
Lao PDR	Champassak	Pathoumphone	Thobsok	2020-11-14	20
Lao PDR	Vientiane Capital	Park Nguem	Fung Daeng	2021-03-24	20
Lao PDR	Vientiane Capital	Park Nguem	Park Kuang	2021-03-23	20
Lao PDR	Vientiane Capital	Park Nguem	Xieng Lae Tha	2021-03-25	20
Lao PDR	Vientiane Capital	Sangthong	Nongbua	2021-03-26	11
Lao PDR	Xayyabouly	Kenthao	Ehoum	2021-04-03	20
Lao PDR	Xayyabouly	Kenthao	Parkkhaem	2021-04-05	20
Lao PDR	Xayyabouly	Paklay	Buaban	2021-03-31	20
Lao PDR	Xayyabouly	Paklay	Sivilay	2021-04-01	20

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Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Erik Delaquis, Vanya Slavchevska, Chea Sareth, and Chanphasouk Tanthapone. The first draft of the manuscript was written by Erik Delaquis and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability Full anonymized replication data is available for this work. The English language version of the auction survey, dataset including survey responses and matching auction data in tabular format, and explanatory code book are available through the Alliance of Bioversity International and CIAT open access dataverse portal: https://doi.org/10.7910/DVN/JMEIAB.

Declarations

Ethics The methods, data collection, and data handling protocols of this project were reviewed and approved by the International Center for Tropical Agriculture (CIAT) Institutional Review Board, and meet CIAT guidelines for research involving human subjects (approval number 2020-IRB03). All respondents provided oral informed consent prior to survey implementation and auction participation, and all personally identifying data have been anonymized in the resulting dataset.

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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Paul C. Struik is Professor emeritus Crop Physiology at Wageningen University & Research in the Centre for Crop Systems Analysis. Dr. Struik has a track record in grassland science, agronomy and crop physiology. Over the last decade the main focus of his research activities were on the following topics:

- Seed systems, especially of vegetatively propagated crops. Currently the focus is on developing quality declared seed systems of root and tuber crops in Eastern Africa, Asia and South America.
- Agrobiodiversity, including the anthropological aspects of the use of diversity in staple crops and the global conservation of genetic resources and crop wild relatives.
- Linking ecophysiology and genetics of complex traits through modelling with a focus on resource use efficiency and stress tolerance.
- Modelling of C3 and C4 photosynthesis at different scales and in different dimensions.