Agriculture and Human Values
https://doi.org/10.1007/s10460-024-10623-x

Contribution of local knowledge in cocoa (*Theobroma cacao* L.) to the well-being of cocoa families in Colombia: a response from the relationship

Gustavo Adolfo Gutiérrez Garcia[1,2,3] · Isabel Gutiérrez-Montes[4] · Juan Carlos Suárez Salazar[1,3] · Fernando Casanoves[2,4] · David Ricardo Gutiérrez Suárez[1,3] · Héctor Eduardo Hernández-Núñez[1,3] · Cornelia Butler Flora[5] · Nicole Sibelet[6,7]

Accepted: 23 July 2024

Abstract

The concept of well-being of rural families is part of a theory under construction in which new theoretical elements are constantly being incorporated. This research aims to determine the influence of farmers' knowledge on the well-being of cocoa growing families in the departments of Santander, Huila, Meta and Caquetá, Colombia. Four categories of farmers were identified with different levels of knowledge in the management of cocoa cultivation obtained through a cluster analysis. The well-being of cocoa farmers, understood as the balance in the capital endowment of rural households, was obtained through the application of a semi-structured interview with 49 variables of human, cultural, social, political, natural, built, and financial capitals. The results show that cocoa knowledge is heterogeneous in the study area, with a slight improvement towards harvesting, post-harvest and transformation links. There is a positive relationship between cocoa knowledge and the well-being of cocoa farming families. Thus, producers with greater integral knowledge, with emphasis on post-harvest and bean transformation links, showed greater well-being. The Random Forest analysis identified that human capital (political, social, human, and cultural) made the greatest contribution to well-being. The findings show that cocoa knowledge contributes to the well-being of rural households to the extent that it favors vertical relationships (linkages with local governments) and horizontal relationships of producers (participation of association managers, sharing knowledge with friends, neighbors and partners, and cocoa training).

Keywords Cacao farmers · Agriculture · Community capitals framework · Cocoa training

Abbreviations

CKI	Cocoa knowledge index
WBI	Well-being index
HC	Human capital
NC	Natural capital
CC	Cultural capital
BC	Built capital
SC	Social capital
PC	Political capital
FC	Financial capital
IPPM	Integrated pest and disease management
GAP	Good agricultural practices
ZOMAC	Areas most affected by the conflict

✉ Gustavo Adolfo Gutiérrez Garcia
g.gutierrez@udla.edu.co

1 Programa de Ingeniería Agroecológica, Facultad de Ingeniería, Universidad de La Amazonia, Florencia-Caquetá, Colombia

2 Doctorado en Ciencias Naturales y Desarrollo Sustentable. Facultad de Ciencias Agropecuarias, Universidad de La Amazonia, Florencia-Caquetá, Colombia

3 Centro de Investigaciones Amazónicas CIMAZ Macagual César Augusto Estrada González, Grupo de Investigaciones Agroecosistemas y Conservación en Bosques Amazónicos-GAIA, Florencia, Caquetá, Colombia

4 CATIE—Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba 30501, Costa Rica

5 Department of Sociology and Criminal Justice, Iowa State University, Ames, IA 50011-1070, USA

6 CIRAD, UMR Innovation, 34398 Montpellier, France

7 INNOVATION, Univ Montpellier, CIRAD, INRAE, Montpellier SupAgro, Montpellier, France

Published online: 22 November 2024

IKEP	Producers with integral knowledge with emphasis on production links
IKEBT	Producers with integral knowledge with emphasis on beneficiation and transformation links
PKDP	Producers with partial knowledge with deficiencies in production links
PKDBT	Producers with partial knowledge with deficiencies in beneficiation and transformation links

Introduction

Cocoa (*Theobroma cacao* L.) cultivation represents the livelihood of between 4 and 5 million people (Voora et al. 2019) in 61 tropical countries (Nieves-Orduña et al. 2023), located in the sub-equatorial fringe of the continents of Africa, Asia, and America (Arvelo et al. 2017). These continents produce 63.2%, 17.4% and 14.1% of the world's cocoa beans (Abbott et al. 2018). In their order, the main producing countries are Ivory Coast, Indonesia, Ghana, Cameroon, Ecuador and Nigeria (Kehinde et al. 2024). This activity is generally supported by small producers (Díaz-Montenegro et al. 2018), who in turn constitute the weakest link in the value chain given the limited access to basic social services, the weakness in institutional accompaniment (ICCO 2022) and the inequity in the distribution of profits, understanding that cocoa farmers receive only between 3 and 6% of the commercial value of a processed product (Voora et al. 2019), while 70% benefits large bean processing companies (Ríos et al. 2017).

In Latin America and the Caribbean, cocoa cultivation directly links 1.7 million small and medium producers with deficiencies at the level of infrastructure, marketing and inability to negotiate collectively (Sánchez et al. 2019). In terms of planted areas, Brazil (40%), Ecuador (24%), Colombia (9%), Dominican Republic (9%), Peru (6%) and Venezuela (4%) are the countries with the largest contribution (Zapata-Alvarez et al. 2024). Colombia, between 2015 and 2020 went from 165,006 ha^{-1} to 189,185 ha^{-1} of cocoa through illicit crop substitution programs with 65,341 cocoa growing families settled mostly in ZOMAC municipalities (areas most affected by the conflict) (MADR 2021). This agricultural activity is carried out in a subsistence production model (Tuesta et al. 2014), developed by farmers of advanced age and low level of schooling (Pabón et al. 2016), who must overcome adverse factors such as the aging of plantations (González-Orozco and Pesca 2022; Jaimes et al. 2022), planting patterns with high and complex densities (Hernández-nuñez et al. 2024), which lead to a high incidence of pests and diseases (Djuideu et al. 2021; Carvajal et al., 2022), poor crop management and little technological development (Báez et al., 2022).

Despite this scenario, the cocoa year 2020–2021 reached a record production of beans in the country with 70,205 tons, being the July–September quarter of 2021, the quarter of highest production with 13,830 ton, which represented a growth of 29% over the same quarter of the previous year (AGRONET, 2021a). This led to an increase of 4.9% in bean exports and 7.1% in derivative products or transformation, particularly chocolate and cocoa butter (FEDECACAO 2022b). This evolution in exports is given at a time when the chocolate industry has started to grow very rapidly in the world (ICCO 2021), with annual increases of 3% (Beg et al. 2017) due particularly to a 40% increase in the value of the bean (Wessel and Quist-Wessel 2015) and emerging markets such as China and India (Singh et al. 2019). These results reflect the first impacts of a national institutional commitment to position cocoa as the crop of peace with the entry of the Peace Accords in 2016 (De la Peña and Granados 2023). Thus, cocoa is part of the government's productive commitments, especially the National Competitiveness Policy, which aims at its productive transformation through the implementation of 15 action plans, including those incorporated by the National Planning Department (NPD) and CONPES 3597 and 3866 (Cristancho-Pinilla et al. 2021). Recently, the agreement for the competitiveness of the cocoa-chocolate chain was officially updated, projecting a production of 126,000 ton of beans by 2030, which will guarantee the supply of the domestic market (table chocolate, fine and artisanal chocolate) and position exports in international markets with flavor and aroma characteristics (SAC 2022).

However, positioning the cocoa chain in Colombia has not been an easy task, given the high geographical dispersion, the absence of a deep-rooted cocoa culture (Espinoza 2016), price instability, and market monopolization by large chocolate industries such as Nutresa S.A (formerly Nacional de Chocolates S.A) and Casa Luker, who acquire 90% of the national production (Ramírez Montañez et al. 2019). These commercial conditions mean that the economic resources obtained do not have a sufficient impact on improving the living conditions of cocoa farmers (Jaimes et al. 2022), which discourages them from continuing to grow cocoa, putting the crop at risk and increasing the possibility of a change in land use (Bunn et al. 2019; López-Cruz et al. 2021; Hashmiu et al. 2022).

For Lee and Park (2023), volatility in market prices and the vulnerability of cocoa farmers' livelihoods become critical threats to sustainable cocoa production. In addition, extreme changes in weather patterns significantly affect cocoa productivity (Asitoakor et al. 2022; Kosoe and Ahmed 2022). This implies the need for public policies aimed at reducing the socio-productive vulnerability of cocoa-growing families through the generation of adaptive capacities to extreme changes by improving the provision of basic social services such as education and health (Baffour-Ata et al. 2023).

The obstacles and limitations faced by rural communities in Colombia represent realities of their existence (Ocampo 2015). However, as adverse as this scenario may seem (De la Peña and Granados 2023), their livelihoods provide them with capabilities, assets (including material and social resources) and activities required for household sustenance and overcoming poverty (Chambers and Comway 1992). According to Emery and Flora (2006), there are three types of resources: 1. those that are consumed, 2. those that are conserved and stored, and 3. those that can be used as an investment and that give rise to more resources in the short, medium, or long term. This third type of resource is called community capital and has been divided into two large groups: human (which includes social capital (SC), human (HC), cultural (CC), and political (PC)) and material (natural capital (NC), financial (FC), and built (BC)) (Flora et al. 2004). Livelihoods are based on these capitals (Gutierrez-Montes et al. 2009), which are sustainable to the extent that they can cope with and recover from stresses and shocks by maintaining the capacities, both today and in the future, of households without compromising the natural resource base (DFID 1999).

Cocoa cultivation is the second most important livelihood in the rural dynamics of farmers in Colombia, after coffee (Cristancho-Pinilla et al. 2021). However, unlike coffee, cocoa has been considered a climate-smart crop (Nasser et al. 2020; Maguire-Rajpaul et al. 2022), given its ability to adapt to climate changes and its contribution to atmospheric carbon fixation (Hernández et al. 2021). Such capacity to cope with climate variability is associated with livelihood diversification (Beltrán-Tolosa et al. 2022) and a greater endowment of human, cultural, built, and financial capital (Bernal et al., 2023). Other studies with cocoa farming families have documented that an adequate endowment of human, cultural and built capital contributes to an improvement in the agronomic conditions of cocoa cultivation and thus the well-being of rural families (Hernández-Núñez et al. 2020).

Based on the subjectivity and diversity of well-being concepts (Durayappah 2011), and therefore the difficulty of unifying a theory of well-being (Lambert et al. 2020), authors such as Hernández-Núñez et al. (2021) constructed a well-being indicator based on the balance of capital in cocoa-growing families in Colombia, which had human capital as the main driver of well-being. The main asset of small cocoa producers is themselves and their families, quantifiable through variables such as "labor forcé" or "availability of labor" (Chambers 1989). Their recognition, monetary or social, is dependent on the endowment of the household's human capital, in particular their level of knowledge (Morse and Mcnamara 2013).

Knowledge theory differentiates between scientific knowledge (Raymond et al. 2010) and local knowledge, the latter including traditional, indigenous, or popular knowledge (Zinyeka et al. 2016; Hill et al. 2020). Within local knowledge, farmers' knowledge is distinguished as a set of skills and practices that allow them to manage their crops in each context (Šūmane et al. 2018). This knowledge is dynamic and complex, the product of a historical construction of peoples or communities with shared experiences (Beckford and Barker 2007). Due to its nature of collective construction, this knowledge allows the farming family to cope and adapt to changing environments, such as those given by climate, economics, among others (Naess 2013).

The present study focused on exploring the level of cocoa knowledge and its relationship with the well-being of rural families, understood as a balance in the capital endowment of the farming community (Hernández-Núñez et al. 2022) in four departments of Colombia: Santander as the main producer of the bean in the country (Cáceres et al. 2021), Huila as the oldest region in commercial bean production (González-Orozco and Pesca 2022), and Caquetá and Meta in the Amazon region, areas heavily hit by armed violence (Cantillo and Garza 2022), with predominance of coca (*Erythroxylum coca*) crops (Ciro 2018; Murillo-Sandoval et al. 2021). In the face of which cocoa cultivation emerges as a licit productive alternative (Rodríguez-de-Francisco et al. 2021). For this study, the research question was oriented to determine the impact of knowledge of management practices in cocoa cultivation on the well-being of rural households. It was expected that the research results informed decision making for future rural extension programs with cocoa growing families.

Materials and methods

Study area

The study was conducted in 22 municipalities in the departments of Santander, Huila, Meta, and Caquetá, Colombia (Fig. 1). These departments were taken as representative of the natural regions of greatest importance for cocoa cultivation, both in terms of production, as is the case of Santander, the leading cocoa bean producer in Colombia (28,037 ton), Huila fifth (3509 ton) and Meta eighth (2239 ton) at the end of 2021 (FEDECACAO 2022a); and in terms of growth in cocoa inventory. In this last indicator, while the growth of established areas in Colombia, increased by 42% between 2008 and 2016, these figures for the department of Caquetá in the same period of time, indicate a growth of 198%, especially through crop substitution programs of

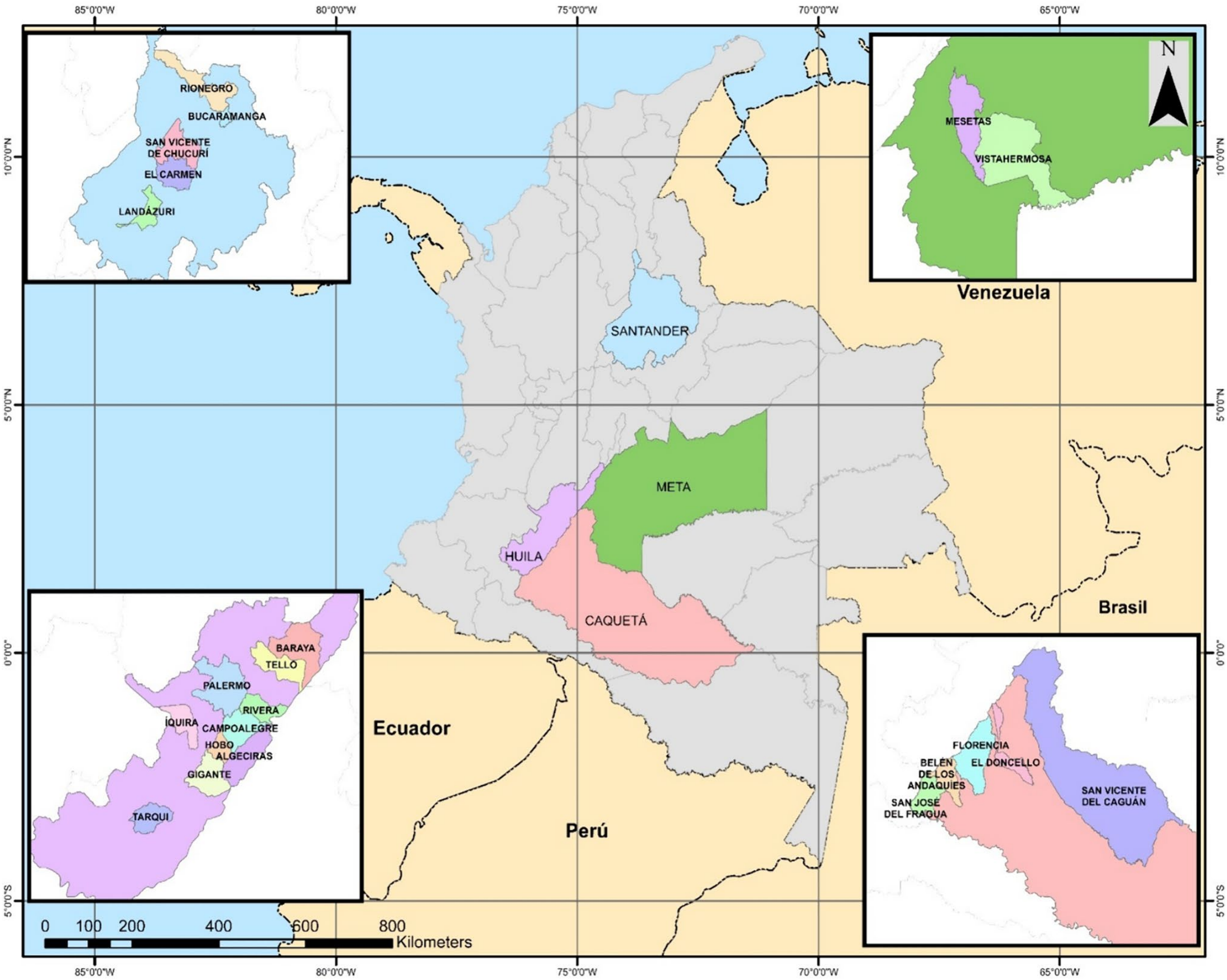

Fig. 1 Study area

illicit use (FEDECACAO 2018). The municipalities were selected based on the participation of cocoa cultivation in the productive dynamics, considering: (a) planted area, (b) bean production, (c) marketing or processing, and (d) presence of cocoa organizations.

Geographical, environmental and productive context

Department of santander Santander is the department with the largest area of cocoa plantations (59,711 ha^{-1} as of 2020) (MADR 2021) and therefore the largest cocoa bean production in Colombia (Cáceres et al. 2021). For the year 2021, it participated with a production of 28,037 ton of grain, which represented 40.6% of national production (FEDECACAO 2022b). The Department of Santander is located in the northeast of the country in the Andean region, between the geographical coordinates 05°42′34'' and 08º07′58'' north latitude, and 72º26' and 74º32' west longitude. It covers an area of 30,537 km^2, equivalent to 2.7% of the national territory. Cocoa plantations range from 90 m a.s.l in the municipality of Barrancabermeja to 1238 m a.s.l in Pinchote (FEDECACAO 2022a). However, the municipalities with the greatest relevance in terms of production and cultivated area are: San Vicente de Chucurí, El Carmen de Chucurí, Rionegro, Landázuri, El Playón and Cimitarra (Pabón et al. 2016). These crops extend over the Montaña Santandereana region, which has a warm humid climate with favorable conditions for cocoa cultivation (Jaimes et al. 2022). According to Mantilla et al. (2000), this zone has a bimodal rainfall regime, which ranges between 1600 and 2500 mm per year with a monthly average of 80 mm, a temperature between 23 °C and 28 °C, a relative humidity of 75–80% and sunshine of 1400 to 1800 h per year. These values are close to the requirements for optimal crop development, such as rainfall between 1200 and 2600 mm, temperatures between 24 °C and 28 °C and high relative humidity above 50% (Charry and Vélez, 2021).

Department of huila The department of Huila is located in southwestern Colombia, between 3º55′12" and 1º30′04" north latitude and 74º25′24" and 76º35′16" west longitude, in a dry tropical forest ecosystem characterized by the Magdalena River valleys (Ordoñez and Rangel, 2021). Huila's surface area comprises 19,890 km^2, which corresponds to 1.8% of the country's total surface area. 53% of these areas are dedicated to agricultural activities (UPRA 2016). Cocoa plantations are located in areas of dry inter-Andean valley, with rainfall below 1,500 mm, altitudes below 900 m and a flat-rolling topography (Ramírez Chamorro et al. 2020a). Cocoa-growing activity is concentrated in 10 municipalities, with Campoalegre, Rivera, Algeciras and Hobo having the highest participation (Ordoñez-Espinosa et al. 2020). According to Briceño (2017), by 2016 this department had 56,785 ha^{-1} in cocoa, of which 32,788 ha^{-1} presented a slight precipitation deficit and temperatures below the crop's optimum, which brings with it the need to implement irrigation systems. These conditions mean that rural households in the department of Huila are affected by climate variability, particularly cocoa-producing families, a livelihood that is highly sensitive to water stress (Bernal et al. 2023).

Department of meta The department of Meta is located in the central-eastern sector of Colombia between 04º54′25" and 01º36′52" north latitude and 71º4′38" and 74º53′57" west longitude (Gómez-Moncada et al. 2022). It has an area of 85,635 km^2, which represents 7.5% of the national territory. This characteristic region of the Eastern Plains has an average annual rainfall of 2000 mm in the central part and 3000 mm in the eastern fringe, with temperatures ranging between 24 °C and 28 °C in the plains and between 8 °C and 20 °C in the foothills (Portilla and Selvaraj, 2020). Physiographic units can be differentiated as mountain zones with an altitudinal gradient between 700 and 3000 m, a pre-mountain range subregion that varies between 300 and 700 m, and savanna landscapes, floodplains and the Amazonian transition below 300 m (González-Orozco et al. 2020). The foothills of the Eastern Plains are being affected by interannual rainfall events, strong storms and extreme temperatures, which cause fragmentation and expansion of climatic space (González-Orozco et al. 2021). In this region of the Eastern Plains, cocoa cultivation is a historical activity with reports since the seventeenth century (Espinoza 2016), initially in areas adjacent to the Meta, Metica and Yucao rivers, until around 1970 when it expanded to the llanero foothills and the upper basin of the Ariari River. Currently, it has positioned itself in the Macarena region in the south of the department of Meta in areas of environmental and strategic importance, in particular, for maintaining an important potential of forest areas with buffer function of the national natural parks: Sierra de la Macarena, Tinigua, Cordillera Picachos and part of Sumapaz (Ceron et al. 2018). In the department of Meta, 27 of the 29 municipalities produce cocoa beans in 1,180 ha^{-1}, linking approximately 2500 families associated in 25 producer organizations, which by 2021, reached a production of 2,239 ton, representing 3.53% of national production (FEDECACAO 2022a). On February 8, 2024 in Amsterdam, Netherlands, the international Cacao of Excellence contest recognized a cocoa sample composed of a FEAR5 and FSV41 cocoa pod as the best cocoa in the world in the GOLD category, an award received by five producer organizations associated with the WORKAKAO multiactive cooperative in the agricultural cocoa node in the department of Meta (Cacao of Excellence 2024).

Department of caquetá The department of Caquetá is located in southeastern Colombia and northwest of the Amazon region between 00º42′17" south latitude and 02º04′13" north latitude and 74º18′39" and 79º19′35" west longitude, representing 7.79% of the Colombian territory. The climate is classified as tropical rainforest type Af (Koppen classification), with an average annual temperature of 25.5 °C and precipitation of 3793 mm (Bermeo et al. 2022). Its geographical position as a transition between the foothills of the eastern Andes mountain range and the Amazon biome makes it a water-producing region for the Amazon River basin (Ciro 2018). Cocoa plantations are generally found planted in mountainous areas, given that piedmont areas with flat to undulating topography are used for cattle ranching (Rodriguez et al. 2021). This makes cocoa production a small-scale activity, with a share of 1.7% of national production, although in relatively large farms with an average of 40 ha^{-1}, higher than the national average of cocoa farms in Colombia (15 ha^{-1}), but with an average planting of 2 ha^{-1} below the national average (2.6 ha^{-1}) (Diaz et al., 2023). According to figures from the second level trade organization, the Asociación Departamental de Cultivadores de Cacao y Especies Maderables del Caquetá ACAMAFRUT, the municipalities with the highest participation in planting and production are, in order, San Vicente del Caguán, Florencia, El Doncello, Puerto Rico, Cartagena del Chaira, La Montañita, San José del Fragua, Belén de los Andaquíes and Solano. Each of the above are recognized as ZOMAC municipalities (areas most affected by the conflict), where extensive cattle ranching and the presence of illicit coca crops have generated environmental problems such as deforestation and forest degradation (Fawcett et al. 2022; Lapola et al. 2023), to which the cultivation of cocoa has emerged as a replacement alternative (Barrera-Ramírez et al. 2019) and forest conservation (Castro-Nunez et al. 2020).

Stages of the investigation

Level of cocoa knowledge

In the 22 study municipalities, an articulation was carried out with the social base organizations, among them, the Federación Nacional de Cacaoteros (FEDECACAO), the Red de Asociaciones de Productores de cacao del Huila (APROCAHUILA), the Cooperativa Agroindustrial de Cacaoteros del Meta (CACAOMET) and the Asociación Departamental de Cultivadores de Cacao y Especies Maderables del Caquetá (ACAMAFRUT) for the development of this research. Based on the lists of associates, the organization proceeded to make an open call for participatory construction spaces through telephone calls and WhatsApp messages. As a result of this call, 268 cocoa producers in the four departments participated voluntarily between 2018 and 2021 (Table 1). Our sample does not correspond to a random sampling, but rather to a participation at the will of the producers. The discretion that producers had to attend the spaces convened allowed us to obtain a heterogeneous sample free of biases of convening those producers with a higher level of knowledge or those with a higher production of cocoa beans. The 268 cocoa producers were involved in the participatory action research methodology proposed by Gutiérrez et al. (2020), which evaluated the level of knowledge in nine links of the cocoa value chain (crop design, clone, soil fertility, pruning, integrated pest and disease management (IPPM), good agricultural practices (GAP), harvest, post-harvest and processing) through multiple choice questions with a single answer. This methodology was called Cacota test, which corresponds to an adaptation of the box test used in the evaluation stage of Farmer Field Schools (ECAS) (Davis et al. 2012; Sanchez and Gamboa, 2014).

This test was adapted to be applied internally in cocoa farms and harmonized as a festival so as not to be perceived as a test of knowledge, but as a recreational activity. Cacota test was used because the methodology is adapted to be applied in remote rural regions where there are limitations for the use of electronic elements such as videobeam or computers. The application of the questions was accompanied by personnel who read the questions aloud to people with

Table 1 General statistics of participating cocoa producers in each municipality and department

Department	Municipality	Number of participants	Woman (%)	Men (%)	Average age (Years)	Average cocoa experience (Years)	Average area in cocoa (ha^{-1})
Santander	Bucaramanga	5	40	60	55.6	23.4	2.1
	El Carmen de Chucurí	19	37	63	49.5	24.6	5.9
	Landázuri	12	58	42	43.0	17.8	3.6
	Rionegro	12	09	91	54.4	22.7	4.4
	San Vicente del Chucurí	21	29	71	48.2	25.2	4.8
	General	69	34	66	49.2	23.2	4.7
Huila	Algeciras	10	20	80	61.9	8.5	2.2
	Baraya	5	40	60	67.5	17.4	1.9
	Campoalegre	10	40	60	68.3	16.7	2.4
	Gigante	3	67	33	56.3	5.7	2.5
	Hobo	6	33	67	58.2	19.7	2.6
	Íquira	8	25	75	65.7	23.0	2.9
	Palermo	13	31	69	57.5	20.5	2.1
	Rivera	11	27	73	55.2	22.4	3.2
	Tarqui	8	13	88	66.0	21.6	2.2
	Tello	21	33	67	60.2	21.2	3.0
	General	95	31	69	61.3	18.8	2.6
Meta	Mesetas	14	43	57	55.6	10.5	2.5
	Vista Hermosa	43	23	77	50.9	4.6	2.3
	General	57	28	72	52.1	6.0	2.4
Caquetá	Belén de los Andaquíes	3	33	67	61.5	8.7	2.0
	El Doncello	12	23	77	54.5	7.8	2.5
	Florencia	13	8	92	56.6	13.1	2.2
	San José del Fragua	14	15	85	57.6	4.6	2.5
	San Vicente del Caguán	4	50	50	67.0	4.2	1.7
	General	46	20	80	57.2	8.1	2.3

visual limitations or who simply could not read. The use of images facilitated the identification of symptoms of pest and disease attacks and the proper use of protective materials and equipment in the post-harvest and processing stages.

The level of knowledge in each link was expressed in values of [0.1] as the proportion of correct answers in relation to the total number of questions. The overall cocoa knowledge index (CKI) was the sum of the [0–1] ranges for each of the nine links. The knowledge rating scale proposed by Gutiérrez-García et al. (2023) (under evaluation) was used, in which an CKI greater than or equal to 0.7 corresponds to a superior rating; CKI between 0.6 and 0.69 an acceptable rating; CKI between 0.51 and 0.59 a poor rating; and CKI below 0.5 a critical rating.

Capital endowment and well-being index of cocoa-growing households

A semi-structured interview was applied to the same cocoa farmers (n = 268) to whom the CKI was initially identified. This data production technique incorporated 49 variables (Table 2) to determine, at the household level, the endowment of human (HC), natural (NC), cultural (CC), built (BC), social (SC), political (PC) and financial (FC) capital (DFID 1999; Emery and Flora, 2006; Gutierrez-Montes et al. 2009). This instrument incorporated the following components: I. General aspects: both of the farmer and the farm, II. HC: rural family members and physical or mental impediments to work in the field, III. NC: at the farm level, including the relationship of crops and accompanying species, as well as the strategic ecosystems present on the farm, IV. CC: Includes motivations, symbols and projections of his practice as a cocoa farmer. It also identifies IPPM practices, weed control, soil fertility, pruning, harvesting and post-harvesting. V. BC: refers to access to basic household services, housing infrastructure and productive systems, VI. SC: Membership and permanence in associative community processes and other activities of interaction with their community, VII. PC: Representation in decision-making spaces at the village level and other community leadership processes. This includes the capacity and ease of dialogue with municipal and departmental authorities, VIII. FC: Economic income and financial capacity.

The variables were selected from studies that evaluated capital endowment in cocoa producers (Hernández-Núñez et al. 2022; Bernal et al., 2023) and that were related to the level of knowledge following the theoretical approaches developed by the authors in previous research (Emery and Flora, 2006; Gutiérrez-Montes et al., 2009; Gutiérrez et al., 2020; Hernández-Núñez et al. 2021). The interviews were conducted by a single interviewer on the farm of each cocoa producer with a duration of 1.5 h. The process involved 20 interviewers linked to research projects of the Universidad de la Amazonia, who were trained and supervised by the research team of experts. The interviewers sent the data from each farm to the coordinator of the research team, who finally cleaned the database and organized the variables. The variables were transformed into intervals [0,1] and summed to determine a subscript for each capital. The subindexes were transformed into [0,1] intervals and summed to generate the well-being index (WBI) (Suárez et al. 2021; Hernández-Núñez et al. 2022). The WBI was expressed in [0,1] intervals. Textual quotes obtained from semi-structured interviews, as used in the capital endowment study of Hernández-Núñez et al. (2021), were used to express cocoa farmers' perceptions of aspects of local knowledge and rural household well-being.

Data analysis

A hierarchical cluster analysis (Ward method and Euclidean distance) was performed using the CKI and the level of knowledge per link to identify a producer type (Sibelet et., 2013). Hierarchical cluster methods allow obtaining dendrograms from which the researcher can decide how many groups to retain. Ward's method produces well-defined groups that are balanced in the number of producers per group. To determine the differences between the groups on CKI, the capital endowment (variables and subindices) and the WBI, an analysis of variance was performed using Linear Mixed Models (LMM) (Di Rienzo et al., 2011) with producer type as a fixed effect and the random effect of department for 20 continuous variables. Linear mixed models with a random effect of department allow us to compare differences between producer types even when not all groups are in all departments.

Generalized Linear Mixed Models (GLMM) (Di Rienzo et al. 2011, 2017) was used for 30 count variables of the capital endowment, using a Poisson distribution for the error term. The assumptions of the models were evaluated by graphical inspection of the residuals. The LSD Fisher test ($p < 0.05$) was used to detect differences between types. A Pearson correlation analysis was performed between the CKI and the WBI. The association between seven presence-absence variables and producer types was analyzed using contingency tables. Finally, a multiple factor analysis was performed to identify the variables with the highest contribution in components 1 and 2 and a classification analysis using the Random Forest algorithm (Louman et al. 2016) to determine the contribution of the seven capitals to the WBI.

Hierarchical clustering and ANOVA analyses by LMM and GLMM were performed using InfoStat software version 2020 (Di Rienzo et al. 2020). Multiple factorial analysis was performed with the libraries *FactoMineR* (Lê-S and Husson 2008) and *factoextra* (Kassambara and Mundt 2020), and Random Forest analysis was performed using *Random*

Table 2 List of variables used to determine capital endowment (number of variables per capital: Financial 7, Cultural 5, Built 9, Natural 8, Political 6, Social 5, Human 9)

Capital	Variables	Abbreviation	Unit	Type
Financial	Cocoa revenues	Coc_rev	USD	Continuous
	Income leased area	Inc_lea_area	USD	Continuous
	Agricultural income	Agri_inc	USD	Continuous
	Livestock income	Liv_inc	USD	Continuous
	External income	Ext_inc	USD	Continuous
	Total income	Tot_inc	USD	Continuous
	Deed of the property	Deed_prop	Yes, No	Categorical
Cultural	Motivations in cocoa	Mot_coc	Number	Discrete
	Participation in traditional festivals	Part_trad_fest	Yes, No	Categorical
	Cocoa identity	Coc_iden	Yes, No	Categorical
	Roots in agriculture	Roo_agri	Year	Continuous
	Productive diversity	Prod_dive	Number	Discrete
	Access roads	Acc_road	Number	Discrete
Built	Travel time to the city center	Tra_tim_cit_cent	Hour	Continuous
	Electric energy	Elec_ener	Yes, No	Categorical
	Potable water	Pot_wat	Yes, No	Categorical
	Basic services	Bas_serv	Number	Discrete
	Technology level household	Tec_lev_hou	Number	Discrete
	Technological level production systems	Tec_lev_pro_sist	Number	Discrete
	Production facilities	Pro_fac	Number	Discrete
	Cocoa infrastructure	Coc_infra	Number	Discrete
Natural	Water sources	Wat_sou	Number	Discrete
	Importance of water sources	Impo_wat_sou	Index [1–5]	Ordinal
	Forest area	For_area	Hectare	Continuous
	Importance of forest	Impo_for	Index [1–5]	Ordinal
	Fallow area	Fall_area	Hectare	Continuous
	Importance of fallow	Impo_fall	Index [1–5]	Ordinal
	Importance of soil	Impo_soil	Index [1–5]	Ordinal
	Supply of natural resources	Sup_nat_res	Number	Discrete
Political	Participation in the board of directors of the community action board	Par_boa_dir_comm	Yes, No	Categorical
	Time on the board community action board	Tim_boa_dir_comm	Year	Continuous
	Satisfaction leadership in community action board	Sat_lead_boar	Yes, No	Categorical
	Linkages with local governments	Link_loc_gov	Yes, No	Categorical
	Participation of association managers	Part_ass_man	Yes, No	Categorical
	Economic activities	Econ_act	Number	Discrete
Social	Participation of the community action board	Par_comm_act	Yes, No	Categorical
	Community work activities	Comm_wor_act	Number	Discrete
	Community integration activities	Comm_inte_act	Number	Discrete
	Knowledge exchange with family members	Kno_exch_fam	Yes, No	Categorical
	Sharing knowledge with friends, neighbors and partners	Shar_kno_fri_nei	Number	Discrete
Human	Level of schooling in youth	Lev_sch_youth	Year	Continuous
	Cocoa training	Coc_train	Number	Discrete
	Coffee training	Cof_train	Number	Discrete
	Livestock training	Liv_train	Number	Discrete
	Training in other agricultural activities	Train_oth_agri	Number	Discrete
	Satisfaction with cocoa knowledge	Sat_coc_kno	Index [1–5]	Ordinal
	Satisfaction with coffee knowledge	Sat_cof_kno	Index [1–5]	Ordinal
	Satisfaction with livestock knowledge	Sat_liv_kno	Index [1–5]	Ordinal
	Satisfaction with knowledge of other agricultural activities	Sat_kno_oth_agr	Index [1–5]	Ordinal

Forest library (Liaw A, 2002) in R software version 4.3 (R Core Team 2020) following the analyses by Suárez et al. (2021).

Results

Typology of producers according to cocoa knowledge

Four producer types were identified according to cocoa knowledge: producers with Integral Knowledge with Emphasis on Production Links (IKEP); producers with Integral Knowledge with Emphasis on Beneficiation and Transformation Links (IKEBT); producers with Partial Knowledge with Deficiencies in Production Links (PKDP) and producers with Partial Knowledge with Deficiencies in Beneficiation and Transformation Links (PKDBT). The CKI and the level of knowledge in the nine links of the cocoa value chain presented a significant statistical difference ($p < 0.05$) among the four producer types (Table 3). Table 4 shows the geographic distribution of producers in the four types for each department. 53.45% of the producers in the IKEP typology are in the department of Santander, while 63.29% of the producers in the PKDP typology are in Huila and 42% of the producers in the PKDBT typology are in Caquetá. Most producers in the IKEBT typology are in the departments of Huila and Meta (37.04% and 32.10%, respectively).

Integral Knowledge with Emphasis on Production Links IKEP (n = 58, 21.64% of producers): This typology is characterized by having the highest value in the CKI and advanced knowledge in the production links (clone, soil fertility, pruning, IPPM, GAP and transformation); it also presents acceptable knowledge in harvest, deficient in crop design and critical knowledge in post-harvest.

Integral Knowledge with Emphasis on Beneficiation and Transformation Links IKEBT (n = 81, 30.22% of producers): This typology is characterized by occupying the second place in the CKI and presenting the highest values in post-harvest and transformation for the four types. It presents advanced knowledge in transformation and GAP, acceptable in clone, pruning and IPPM, deficient in knowledge of soil

Table 3 CKI and level of knowledge (Average ± standard errors) in links of the cocoa value chain, results of the ANOVA analysis for the four producer types

Variable	IKEP	IKEBT	PKDP	PKDBT	p-valor	General	Coefficient Variation
Crop design	0.53 ± 0.06 a	0.50 ± 0.04 a	0.34 ± 0.05 b	0.34 ± 0.04 b	0.0050	0.43 ± 0.05	23.98
Clone	0.82 ± 0.03 a	0.64 ± 0.04 b	0.36 ± 0.04 c	0.37 ± 0.03 c	< 0.0001	0.55 ± 0.11	41.15
Soil fertility	0.80 ± 0.02 a	0.56 ± 0.03 b	0.55 ± 0.02 b	0.62 ± 0.04 b	< 0.0001	0.63 ± 0.06	18.70
Pruning	0.80 ± 0.03 a	0.62 ± 0.03 b	0.44 ± 0.03 c	0.50 ± 0.03 c	< 0.0001	0.59 ± 0.08	26.65
IPPM	0.88 ± 0.02 a	0.64 ± 0.02 b	0.60 ± 0.02 b	0.63 ± 0.03 b	< 0.0001	0.69 ± 0.07	18.97
GAP	0.77 ± 0.03 a	0.74 ± 0.02 a	0.38 ± 0.03 c	0.59 ± 0.03 b	< 0.0001	0.62 ± 0.09	28.77
Harvest	0.69 ± 0.03 a	0.59 ± 0.02 bc	0.56 ± 0.02 c	0.64 ± 0.03 ab	0.011	0.62 ± 0.03	9.04
Post-harvest	0.50 ± 0.03 a	0.53 ± 0.02 a	0.52 ± 0.02 a	0.22 ± 0.02 b	< 0.0001	0.44 ± 0.07	33.75
Transformation	0.74 ± 0.04 a	0.82 ± 0.03 a	0.73 ± 0.03 a	0.20 ± 0.03 b	< 0.0001	0.62 ± 0.14	45.66
CKI	0.69 ± 0.02 a	0.56 ± 0.01 b	0.40 ± 0.01 c	0.31 ± 0.02 d	< 0.0001	0.49 ± 0.08	34.52

The color signifies the level of knowledge according to the score obtained. Knowledge above 0.7 in green color means advanced rating, knowledge between 0.6 and 0.69 in yellow color means acceptable rating, knowledge between 0.51 and 0.59 in orange color means poor rating and knowledge below 0.5 in red color means critical rating

IPPM integrated pest and disease management, *GAP* good agricultural practices

a, b, c: different letters between rows mean statistical differences according to Fisher's LSD test

Table 4 Absolute (Fa) and relative (Fr) frequency of the four producer types according to cocoa knowledge in each department

Department	IKEP		IKEBT		PKDP		PKDBT	
	Fa	Fr	Fa	Fr	Fa	Fr	Fa	Fr
Santander	31	53.45	14	17.28	11	13.92	13	26.00
Huila	9	15.52	30	37.04	50	63.29	6	12.00
Meta	10	17.24	26	32.10	11	13.92	10	20.00
Caquetá	8	13.79	11	13.58	7	8.86	21	42.00
General	58	100	81	100	79	100	50	100

fertility, harvest, and post-harvest. It presents critical knowledge in crop design.

Partial Knowledge with Deficiencies in Production Links PKDP (n = 79, 29.48% of producers): This typology is characterized by being in third place in the CKI. It has advanced knowledge in transformation and acceptable knowledge in IPPM. It presents a deficient qualification in soil fertility, harvest, and post-harvest. It also has critical knowledge in crop design, clone, and GAP.

Partial Knowledge with Deficiencies in Beneficiation and Transformation Links PKDBT (n = 50, 18.66% of producers): This typology is characterized by the lowest value in the CKI. It presents acceptable knowledge in soil fertility, IPPM and harvest, deficient in GAP and critical knowledge in the links of crop design, clone, pruning, post-harvest and transformation, the latter two being the lowest values in the four types.

Effect of cocoa knowledge on households' capital endowment

There were significant statistical differences ($p < 0.05$) in 16 of the 49 capital variables among the producer types (Table 2). The HC, SC and BC capitals presented 66.7%, 40.0% and 40.0% of their variables with significant differences, respectively; these capitals are most influenced by the level of cocoa knowledge. The PC and NC capitals only presented significant differences in 33.3% and 25.0% of their variables, respectively. The FC and CC capitals did not show significant differences in any of the variables. Producers with integral knowledge (IKEP and IKEBT types) presented better values in BC variables (cocoa infrastructure, technological level production systems and of the rural household). Likewise, it was their households that participated most in training in the different livelihoods and where the young people had the highest level of schooling (HC). In the case of producers with knowledge in beneficiation and transformation links (IKEBT and PKDP types), there were better vertical relationship conditions (PC: linkages with local governments). For producers with knowledge in production links (IKEP and PKDBT types), horizontal relationships are encouraged (SC: knowledge exchange with family members and friends, neighbors and partners and PC: participation of association managers), in addition to favoring water management (NC: number and importance of water sources).

Contributions of cocoa knowledge to the well-being of rural households

The index of well-being and capital balance (WBI) showed a statistically significant difference ($p < 0.05$) between producer types; however, there were no differences between the capital sub-indices (Fig. 2). The IKEBT typology presented the highest WBI, followed by the IKEP and PKDBT

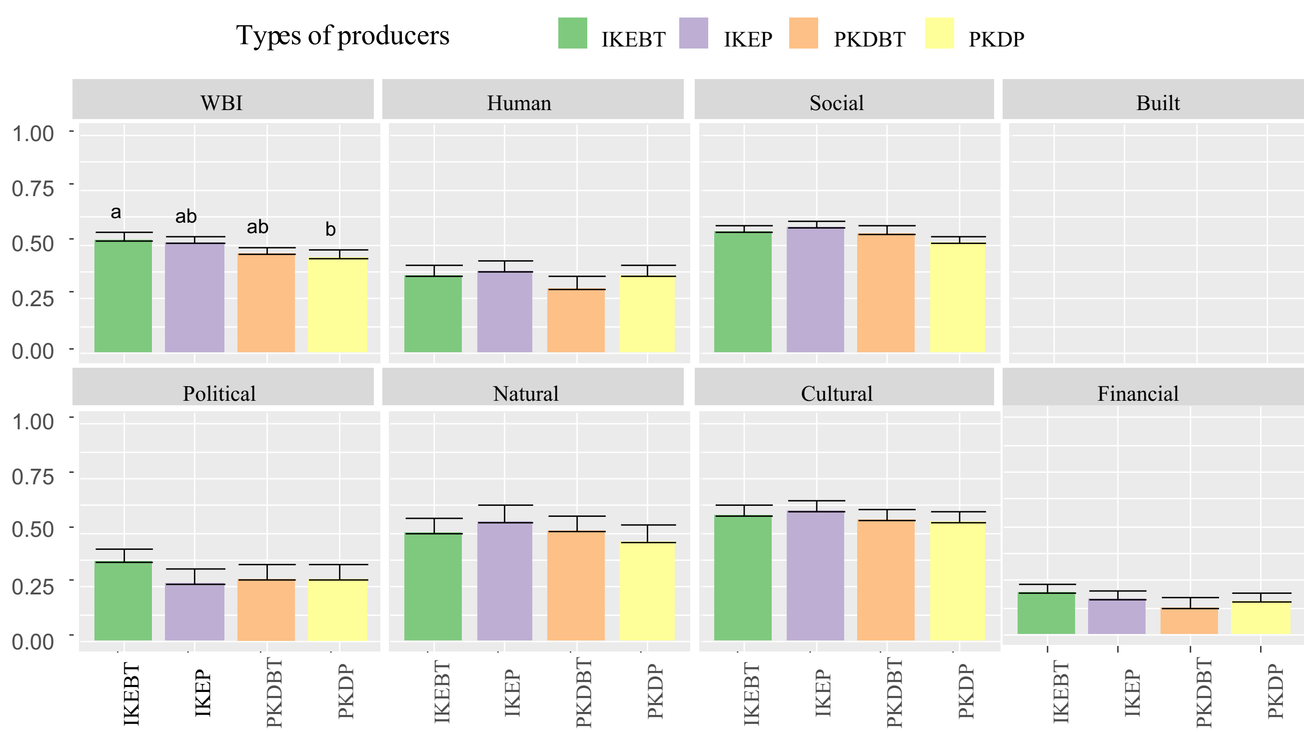

Fig. 2 Average ± standard errors of the WBI and subindices of capital in rural households, results of the ANOVA analysis for the four types of producers

types (Fig. 2). The results of the multiple factor analysis show a greater contribution of six and five variables in components one and two, respectively (Fig. 3a and b). Component one presented the highest contribution of the variable participation of association managers (PC), two BC variables (technological level of the production systems and of the rural household), one SC variable (sharing knowledge with friends, neighbors, and partners) and two HC variables (participation in cocoa training and satisfaction with cocoa knowledge). While component two, the variable linkages with local governments obtained the highest contribution (PC), followed by two NC variables (number and importance of water sources) and two BC variables (cocoa infrastructure and production facilities). According to the Random Forest analysis, the group of human capitals (PC, SC, HC, and CC) present the highest contribution to the WBI (Fig. 3a and b). These findings show that cocoa knowledge contributes to the well-being of rural households to the extent that it favors vertical relationships (linkages with local governments, training) and horizontal relationships (participation of association managers, knowledge exchange with family members and sharing knowledge with friends, neighbors, and partners) of producers.

Discussion

Types of producers according to cocoa knowledge

The types of producers generated by the study are heterogeneously composed of cocoa farmers from the different departments evaluated. We found that regardless of the department, farmers can develop the same cognitive capacities for crop management. These results are like those reported by Congretel and Pinton (2020), who found that local knowledge is a dynamic, adaptive, and political product of the relationship that initially emerges from the local. For Šūmane et al. (2018), this knowledge is the fruit of accumulation over years of personal experiences in dynamic local environments. In this way, knowledge is such a particular condition of the farmer and his community, that authors such as Xu and Zhang (2021), found that only adjustments at the household or village level influence an improvement of knowledge.

Although knowledge is not limited to departmental conditions, there is an association of knowledge on processing and transformation issues with the development of physical infrastructure within the departments. Thus, 70% of the producers that are part of IKEBT are located in the departments of Huila and Meta, which, in turn, according to the

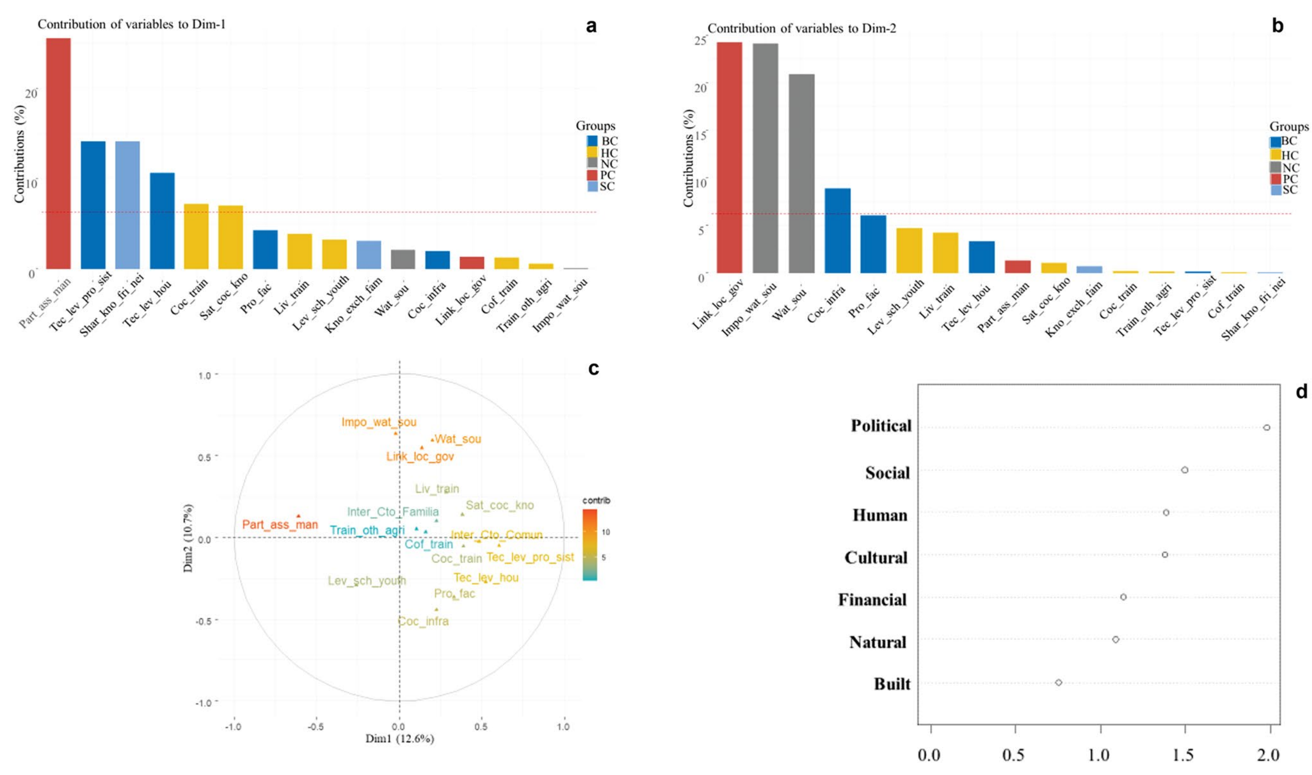

Fig. 3 **a** and **b**: Contribution of the variables for each capital in the principal component 1 and 2. The variables above the dotted line presented the highest contribution, **c**: distribution of the variables in a biplot, **d**: Contribution of the capitals on the WBI

productive characterization study conducted by FEDECACAO, are the regions with the best development in processing infrastructure with 42% and 46% respectively, well above the national average of 35% (FEDECACAO 2022a). However, the issue is not only about infrastructure, as Charry and Vélez (2021) found that all the producers studied have some type of infrastructure for fermentation, even though the quality of the grain is not the best. Such is the case of producers in Santander and Caquetá, who have 53% and 45% respectively, with wooden crates for this process, values above the national average of 44% (FEDECACAO 2022a) and the appropriation of knowledge in processing and transformation processes is not consistent with technological development.

It could be said that the departments of Huila and Meta are regions that have opted for access to specialized niche markets at the export level or "bean to bar" transformations, as in the case of the fine chocolate venture carried out by Carlota Chocolat in the municipality of Girón, Santander, whose four regions supplying grain include the departments of Meta, Arauca, Nariño and Santander itself. Unlike the previous ones, Santander concentrates 53% of the IKEP producers, making it a region that has prioritized the grain production stages over those linked to the quality of the grain. According to FEDECACAO (2022b), in Santander 86% of producers carry out phytosanitary control, 83% manage shade and 84% prune their trees, values that are above the national average and that exceed the departments of Huila, Meta and Caquetá. In part, these data speak of the cocoa growing tradition in the department of Santander and the emphasis that has led it to position itself as the largest cocoa bean producer in Colombia. These values coincide with the results of our study, which found that the links of greatest conceptual dominance are the IPPM, pruning and GAP.

Within producer types, the post-harvest (fermentation and drying) and processing links have played an important role in differentiating between producers with a good level of cocoa knowledge (IKEP and IKEBT) and those with partial knowledge (PKDP and PKDBT). These results speak of the importance in Colombia of knowledge in the grain processing and value-added generation links, so much so that producers with this type of knowledge (59.7%) are slightly in the majority in the study. Although knowledge deficiencies persist in the links that lead to bean production, producers have focused their efforts on improving bean quality and developing semi-processed cocoa-based products.

These results are consistent with the fact that Colombia for the year 2022, although it decreased by 50% in exports of dry beans, increased by 21% exports of semi-processed and processed cocoa-based products (FEDECACAO 2023). From the level of cocoa knowledge, it could be stated that producers recognize that 70% of the profits from producing a chocolate bar are obtained by who transforms (Ríos et al. 2017) and that the exclusive sale of beans only obtains 3–6% (Voora et al. 2019). That is recognized by some of the farmers. "*The cocoa business is in its transformation; as long as we continue to sell only beans, we will never receive the resources to pay for our efforts*" (interview with a cocoa farmer in Caquetá).

These results are consistent with the realities of the departments studied, where there is an exponential increase in the number of enterprises generating added value to the cocoa bean produced. Thus, the department of Huila, which, for this study, has 63% of the producers of the IKEBT typology, have managed to consolidate enterprises for the production of table chocolate and fine chocolate, such as Tolimax, Chocolates Panchi (Neiva), Chocolate Riverense and Chococor (Rivera), Chocacec, Cacao Yoli, Delicias de Nury (Campoalegre), Cavocao chocolatería (Hobo), Chocolates Shalena (Íquira), K-Kacao (Algeciras), Cacao Pitaleño (El Pital), Chocolate Mariano (Nataga), Chocolates La Montaña (Palermo), Chocolate Auténtico (Tello), among others. In the case of the Association of Cocoa Producers of the municipality of Algeciras (APROCALG), according to a leader of the Association, "*we have managed to modernize cocoa farming in Algeciras through the planned planting of cocoa clones, we are the only municipality that can differentiate its quality, which has allowed us to enter international markets such as the Swiss market where we sell 70% cocoa*" (interview with cocoa producer in Algeciras, Huila).

With the exception of PKDBT, the remaining three types of producers (81%) have shown a significant level of knowledge in harvest, post-harvest and transformation links. These results respond to the direction the country is taking towards the search for a differentiated value chain with prevalence of premium quality grains (Ríos et al. 2017; Díaz-Montenegro et al. 2018), where origin characteristics, flavor attributes, quality and organic management, constitute the main differentials (Melo and Hollander 2013). "*With what we produce in Colombia we will not be able to compete in a common cocoa bean market, our neighbor (Ecuador) produces and produces a lot, three, four times what we produce, let alone think about competing with Africans (Ivory Coast, Ghana); we must think about small niche markets especially in countries like the United States and Europeans who pay well, pay for quality*" (interview cocoa producer in Huila).

Producers with comprehensive knowledge with emphasis on production links as well as on beneficiation and transformation links, are cocoa farmers with important cognitive capacities; however, the high coefficient of variation found in this study (Table 3), particularly in links such as transformation, clone, post-harvest, GAP, pruning, IPPM and crop design, is a cause for concern. These results speak of heterogeneity in knowledge, with producers in the same department having advanced knowledge in management practices and others with poor to critical results. A similar study in Ghana assessed the knowledge of 404 cocoa farmers in IPPM, finding that, although farmers seemed to know a lot about pesticide management, 53%, 57% and 79% were unaware of the negative effects of pesticides on food quality, soil quality and human health, respectively (Boateng et al. 2023). In the same country, two other studies aimed to evaluate the knowledge of cocoa farmers in IPPM, the first study found that 85% did not recognize disease symptoms in a timely manner (Awudzi et al. 2021) and in the second, more than 50% of farmers failed to identify pests and symptoms of damage (Amon-Armah et al. 2020).

The heterogeneity in the level of knowledge between and within the departments studied leads us to understand that there are specific dynamics that directly affect the level of knowledge in terms of cocoa crop management. Thus, the department of Huila concentrates 63.29% of the producers with a partial knowledge of the crop and deficiencies in the production links. This condition is being affected by the deficiency in the availability of skilled labor for the development of tasks such as pruning, shade management and disease control practices (Briceño, 2016). This, coupled with an average age of 61 years for this study, means that there is limited vitality to implement certain management practices by their own hands, especially in plantations of hybrid materials older than 40 years, which characterize the cocoa plantations in the department of Huila (González-Orozco and Pesca 2022; Briceño, 2016). The advanced age of cocoa farmers in Huila is consistent with the characterization study conducted by FEDECACAO who found that 53.57% of producers are older than 60 years (FEDECACAO 2022b).

This analysis of the weaknesses surrounding the territorial environments of the areas studied leads us to reflect on the concentration of 42% of producers with partial knowledge and deficiencies in processing and transformation practices in the department of Caquetá. A prevalently cattle-raising department (Polanía-Hincapié et al. 2021; Tebbutt et al. 2021), with a culture rooted in the traditional model of cattle fattening and milk production (Gutiérrez and Hernández, 2018), which strongly takes precedence over other agricultural activities such as cocoa (Díaz et al. 2023). These deficiencies at the cultural level make the existing management models, such as cattle ranching with low labor requirements and technification, contrast with the cocoa model, which is demanding in technification and attention to management practices (Effendy et al. 2019). According to FEDECACAO (2022b) regarding post-harvest practices, 19.3% of producers in Caquetá do not ferment or do so inadequately in sacks (17.48%) and 32.9% dry their beans on surfaces of earth, plastic or sacks, elements that do not guarantee the safety of the finished product.

Effect of cocoa knowledge on households' capital endowment

We found the CKI has generated a greater number of changes in variables and, therefore, a greater incidence in the HC, BC, NC, SC and PC. These results are consistent with recent studies by authors such as Bernal et al. (2023), who found that a balance in capital endowments, and especially a greater endowment of human capital, make cocoa families in the department of Huila, Colombia, more resilient to climate variability. A study of cocoa plantations in eastern Colombia found that human capital was the main driver of rural household well-being (Hernández-Núñez et al. 2022). In China, a study in agrifood value chains found that knowledge sharing, and information flow (HC) are key factors in community resilience (Liu et al. 2023). Consistent with the variable of youth educational level (HC), a study on the adoption of sustainable agricultural practices in northern Colombia found educational level (HC) to be a determining factor.

From the spiraling-up theory proposed by Emery and Flora (2006), our results allow us to infer that to the extent that progress is made in training programs that allow cocoa farmers to have integral knowledge in each of the links of the cocoa value chain, technological processes will be improved in production and household systems (Fig. 4). Producers with a better CKI in the nine links evaluated have manage a better BC (technological level production systems, technological level household, production facilities and cocoa infrastructure), by valuing the importance and necessity of technological developments in improving crop productivity and, therefore, in economic sustainability. These results can be seen reflected in the department of Santander, an area that is home to 53.45% of producers with IKEP, which may be associated with the fact that it is a traditional cocoa-producing region (De la Peña and Granados 2023). With this historical tradition, they have managed to develop both productive infrastructure, such as fermenters and Elba-type dryers, as well as decent rural housing (Ramírez et al., 2019; Baffour-Ata et al. 2023).

The department of Santander contains 30% of the national inventory of cocoa plantations and accounts for 41% of national cocoa bean production (Cáceres et al. 2021). In addition, cocoa is the second most important agricultural crop in the department, after oil palm, and contributes 20,000 rural jobs annually (Jaimes et al., 2022). It has the highest bean yield in the country with 471 kg ha^{-1} year^{-1}, which is above the national average (453 kg ha^{-1} year^{-1}) (FEDECACAO 2022a). In the words of a cocoa farmer in Santander, "*We strive to invest the proceeds of our cocoa harvests in improving housing, which is why you can see beautiful houses, which do not envy any other house in the village*" (interview with a woman cocoa farmer in Santander).

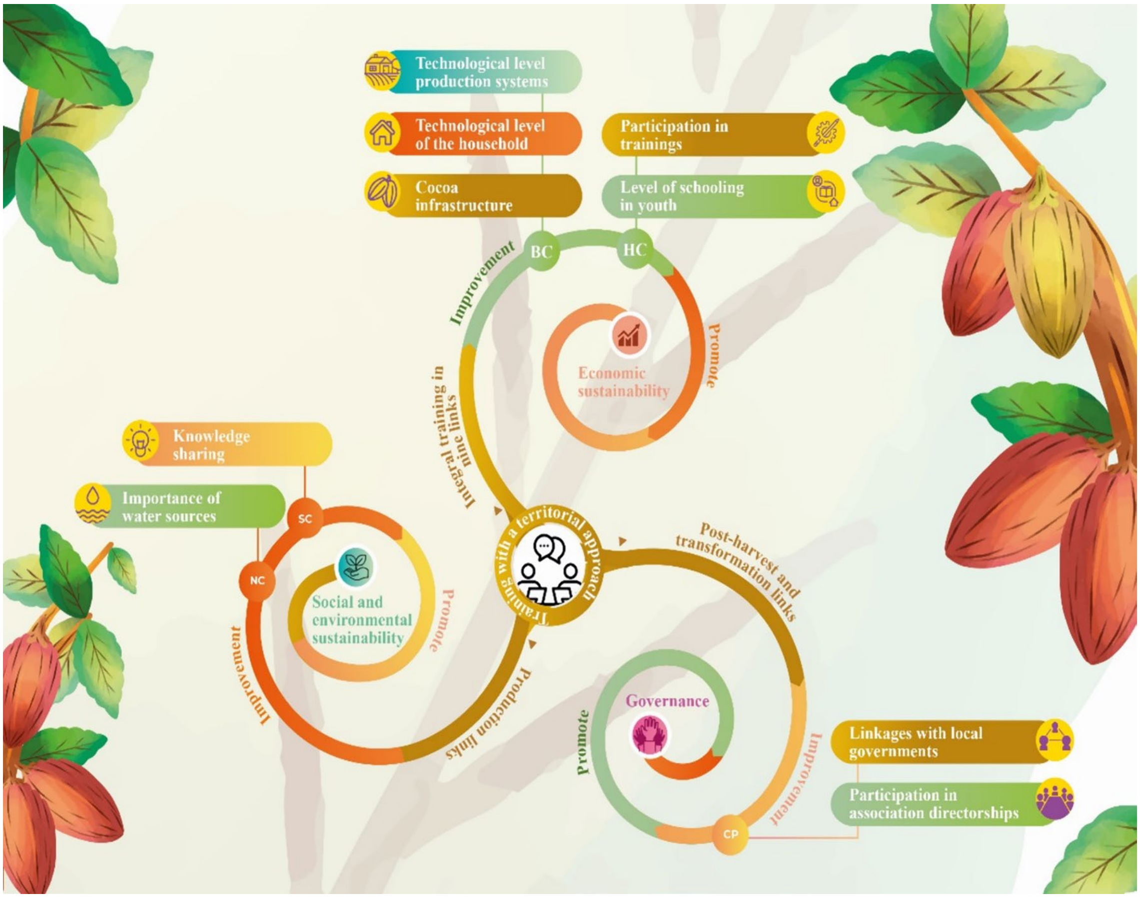

Fig. 4 Training pathways as a spatially adaptive spiral

Higher BC endowment has been associated in rural studies with improved food security (Kabir et al. 2022), livestock management (Bianchi et al. 2022), agricultural production (Engås et al. 2023; Chandio et al. 2023; Shah et al. 2023), including specifically cocoa production (Wongnaa et al. 2021; Osei-Gyabaah et al. 2023; Toledo-Hernández et al. 2023). Our results regarding household technological level are similar to those reported by Zou and Mishra (2020), who found that the level of knowledge was associated with the adoption of household appliances.

The spiraling-up allows us to observe that farmers with integral knowledge in the management of cocoa cultivation have a positive influence on the HC, which makes these farmers tend to improve the level of schooling in children and their participation in training processes in the different livelihoods of the rural household (Fig. 4). This is how these farmers have given greater importance to the academic training of their children. *"I want my children to have the opportunities that I did not have, to go to college and return to the fields, because in many cases, children leave, study and no longer want to return to work with their parents on the farm"* (interview with a woman cocoa producer in Huila).

These results are similar to those obtained by a study in Senegal and Zambia, where it was found that the forms of family transmission of knowledge and the increase in school enrollment were variables linked to positive changes in generational transitions in rural youth (Rodríguez et al., 2023; Girard 2023). In the words of a woman cocoa farmer, *"I keep part of the cocoa harvest to pay for my daughter's tuition, she is studying psychology, and thanks to my crop she is finishing her studies"* (interview with a woman cocoa farmer in northern Huila).

The results show that producers with integral knowledge in crop management value the importance of training processes. "*For me, training is more than an opportunity to learn, it is a place to make friends, to meet other people, to share what I have learned in my crop, to learn about what is happening in my municipality*" (interview with cocoa producer in Meta). A better level of knowledge increases farmers' confidence, satisfaction, and autonomy, which in turn, become strong motivators for further learning (Šūmane et al. 2018). A study of farmers in Zambia found that people with the most experience in the field initially had the lowest level of prior knowledge of pesticide management, but after a training process they had the greatest increase in knowledge (Goeb and Lupi 2021). Paparrizos et al. (2023) and were able to demonstrate that a significant level of knowledge of meteorological phenomena was the result of commitment and capacity building when combining local knowledge and the use of mobile scientific information applications.

In contrast to the integral training processes in each of the links, the training efforts are specifically oriented to the beneficiation and transformation links, and the results obtained can be explained from the spiraling-up theory (Emery and Flora, 2006). Producers improve their vertical relationships, which leads to improved links with local administrations and encourages participation in leadership positions in social-based organizations (Fig. 4). Knowledge of post-harvest and bean transformation provides cocoa farmers with the capacity to govern their own territory together with local institutions. "*It is important to know what the Mayor's Office is doing, because most of the money for the projects can be left on the way, so it is necessary to know what can be accessed*" (Interview with producer in Meta). These capabilities provided by a quality bean, which are fundamental for agroindustrial processes, make producer organizations proactive processes with leadership and self-management capacity. According to Charry and Vélez (2021), in Colombia there are 923 companies in the cocoa sector and its derivatives, of which 199 are dedicated exclusively to bean processing. These companies not only boost employability in the territories, but also offer higher prices to the producer compared to the current market. Supporting these enterprises becomes a challenge for Colombia's institutions, not only in terms of strengthening the agribusiness per se, but also in consolidating a culture of consumption of table chocolate, fine chocolate and other presentations based on cocoa liquor.

To this end, training and qualification processes from the educational and trade sector should support curricula focused on the need to correct inadequate post-harvest handling and processing of cocoa beans. Training processes that at the same time inhibit the apathy of producers for the current training processes (Gutiérrez et al., 2020), with antidotes of direct response to what is desired, needed and demanded by the market. It was found that cocoa farmers with knowledge in post-harvest and processing have not only been heard by state agencies, but have also been able to participate in decision-making bodies such as municipal councils and to be part of electoral contests as candidates for municipal mayors. For example, one of the interviews recorded "*my son aspires to be mayor of Mesetas for the 2020–2023 term. We have lived in the Rosas village all our lives, he studied and knows the countryside very well, and what he needs is the opportunity to support the work of our farmers*" (interview with cocoa farmer in Meta).

A study in the Andean region, department of Huila, Colombia, has shown that variables such as associativity, which is based on political capital, allowed an improvement in the well-being of coffee growing families (Suárez et al. 2021). According to Lee and Park (2023), political capital has been supported by the diversification of actors such as territorial entities (governments and mayors' offices), private enterprise, socially based organizations, and international cooperation. In reference to the role of organizations such as ASOCODEVI in Meta, there were comments such as "*they have supported us a lot, especially in the cultivation part, with fertilizers, training in planting, support in the farms, in short, the whole agricultural process as such*" (interview with a producer in Meta). In the same department, the governor's office of Meta has institutionalized a monthly farmers' market to promote agricultural products. Private initiatives such as MAS Meta, financed by ECOPETROL in association with the Universidad de los Andes, have strengthened the entrepreneurial capacities of small cocoa processing enterprises. *We have received significant support from the MAS Meta project in the design and printing of our packaging to go to market* (interview with woman cocoa entrepreneur in Meta). The participation of cocoa farmers in local cooperatives significantly affects the level of functionality of the training centers (Wonde et al. 2022).

Finally, the spiraling-up theory allows us to understand that if training processes are oriented towards production links, sharing knowledge with friends, neighbors and partners is encouraged and sensitivity to the NC is improved (Fig. 4). Producers with a better level of knowledge in the first links of the value chain (from crop design to grain production) have been able to manage a higher level of SC (knowledge sharing with friends, neighbors and partners and knowledge sharing with family members). These results are like those found by Thomas et al. (2020), who discovered the importance of social relationships in the construction of knowledge in farmers. Knowledge sharing among farmers is the basis for operationalizing policies to improve rural production (Chengalur-Smith et al. 2021; Crawford et al. 2022; Arifah et al. 2023). Likewise, knowledge in production links was associated with NC valuation (water sources, importance of water sources). A better level of knowledge in the different production links recognizes the importance of water sources (NC) both for agricultural activities such as irrigation (Della et al., 2021), cleaning of the processing infrastructure, and for the normal development of household activities (Qiu et al. 2023). Natural capital provides the environmental conditions, the material basis for the sustenance of humanity (Zhang et al. 2023). This is why it is a key element in dynamizing and, at the same time, limiting agricultural production (Taghikhah et al. 2022).

Geographic heterogeneity and forest types in Colombia influence the diversity of cocoa crop establishment patterns (Rojas-Molina et al. 2021). Contrary to the incidence of cocoa cultivation in deforestation dynamics in African countries such as Ghana and Ivory Coast (Ashiagbor et al. 2022; Kalischek et al. 2023), in Colombia, cocoa is a dynamic agent of peasant economies (Sánchez et al., 2015) and a promoter of productive-protective reforestation programs as an alternative to coca crop substitution (Castro-Nunez et al. 2020). Its establishment in association with other agricultural and tree species (Somarriba and Lopez-Sampson 2018; Somarriba et al. 2021) improves the richness and diversity of the edaphic macrofauna and thus the physical quality of the soil (Durán-Bautista et al. 2023).

Contributions of cocoa knowledge to the well-being of rural households

According to the results obtained, the cocoa knowledge index (CKI) among the types did not significantly affect the sub-indices of capitals, but it did affect the well-being index (WBI) of rural households. Contrary to other findings such as those reported by Suárez et al. (2021), for a case study with coffee farming families, the sub-indicators of cultural, financial, built, natural, political, and social capital presented significant differences between types. We consider that the sub-indexes of capitals were compensated among the values of the capital variables. For example, the financial capital sub-index did not show significant differences among the types, because although the income received from cocoa cultivation is different among the producers of the four types, other agricultural (livestock) or non-agricultural income (wages, government subsidies) compensated for the financial sub-index.

The CKI has a significant impact on the WBI of rural households. These results are consistent with studies which show that improved knowledge resulting from the support of rural extension services has an impact on poverty reduction and, therefore, on the well-being of rural households (Acheampong et al. 2023; Onumah et al. 2023). A related study found education level, agricultural experience, training received, and extension services to be significantly influential variables in the adoption of climate change adaptation practices (Belay et al. 2022). A study in Iran found that farmers' knowledge of safe pesticide use was not only important for physical health but also for agricultural sustainability (Sharifzadeh and Abdollahzadeh 2021).

Our study shows a direct relationship between the CKI and the WBI of rural families. To the extent that farmers with Integral Knowledge with Emphasis on Production Links (IKEP) (CKI = 0.69) and farmers with Integral Knowledge with Emphasis on Beneficiation and Transformation Links (IKEBT) (CKI = 0.56) (Table 3) present greater integration of their knowledge, their well-being improves WBI = 0.50 and WBI = 0.52 (Fig. 2), respectively. However, it is observed that even despite institutional efforts at the training level, farmers' cocoa knowledge is still deficient, which is consistent with dissertations exposed by other authors in Colombia (Briceño, 2016; Gutiérrez et al., 2020). This condition directly responds to a deficient level in the well-being of cocoa farming families. Regarding the level of well-being, our results show that the typology with the best knowledge registers a well-being index of 0.52, which is far from what was found by Suárez et al. (2021), who found a maximum well-being of 0.73 in coffee-growing families and Hernández-Núñez et al. (2021), who found a well-being index of 0.59 in cocoa-growing families in the department of Meta, Colombia.

The IKEBT producers presented significant differences with respect to the WBI of the IKEP producers. This allows us to infer that integral knowledge with emphasis on the beneficiation and transformation links of the cocoa bean is having an impact on the improvement of the well-being of cocoa-growing families. For these producers, a vertical relationship prevails with state institutions, both in educational and commercial issues for the positioning of their bean processing enterprises. *"Mujari is a coffee and cocoa transformation enterprise developed by a group of women in the department of Meta that has grown hand in hand with the relationship with public and private entities. We have received support from the government of Meta, the Chamber of Commerce of Villavicencio, SOCODEVI, universities such as the Universidad de los Andes and the Universidad de la Amazonia"* (an interview with woman cocoa producers in Meta).

This relationship allows cocoa organizations to connect with markets (Castro-Nunez et al. 2019), which provides opportunities for social interaction and thus the capacity to establish exchange relationships that go beyond the exclusive payment for a product (De Guzman et al. 2020). In fact, a study of the cocoa chain in southern Colombia identified the need for immediate intervention actions, including associative work and endogenous marketing models (Montoya-Restrepo et al. 2015). An evaluation of cocoa projects in Colombia found that 84.6% of project initiatives have succeeded in demonstrating that cocoa producer organizations maintain linkages with their trading partners (Gil et al. 2023). These results are consistent with those reported by De Boer et al. (2019), who found that expanding the relationship between marketers and producers brings opportunities for improved knowledge and skills. A study in Nicaragua with coffee producers identified how their participation in high-value certified coffee markets promoted new asset creation and improved livelihoods (Donovan and Poole 2014).

Colombia, given its diversity of both genetic material (Rodriguez-Medina et al. 2019) and biogeographic diversity of cocoa planting areas (González-Orozco and Pesca 2022), has sensory profiles with special attributes (Mendoza et al., 2022), which have led to the search for premium market niches (Ríos et al. 2017). By 2022, Colombia increased exports of semi-processed and processed cocoa-based products by 21% (FEDECACAO 2023). *"Thanks to international cooperation in my country, last October 2022, I participated in the "Salon du Chocolat" Paris, France, and I saw how a chocolate bar of 50 g of cocoa from Madagascar, others from Peru or Costa Rica, had a value of 18.5 euros, there I discovered that the key is in the transformation, in positioning products made in international markets" (interview with cocoa producer in Caquetá)"*. This has led local organizations, such as the experience of the Comité de Cacaoteros de los municipios de El Paujil y El Doncello, Caquetá (COMCAP), to explore the positioning of their beans through exports to Europe and the United States. *"In the year 2021 we achieved our first export, 2500 kg to Genoa, Italy; in October 2022 to this same destination, we sent 3500 kg and recently in June 2023, 6000 kg were sent through the port of Amsterdam to Paris. In addition, we send our beans to the United States for the production of a table chocolate which is marketed in this country under the brand name "Ventura"* (interview with COMCAP organization director, Caquetá).

Conclusions

In the four departments studied in Colombia, the CKI of farmers is heterogeneous, with a slight improvement towards harvesting, post-harvest and transformation links, which shows the path that cocoa farming has taken towards the production of beans for flavor and aroma and the incursion into processing enterprises. Producers with more integral knowledge, with emphasis on post-harvest and bean transformation links, presented greater well-being, which shows how undertaking agro-industrial processes based on cocoa beans allows rural households to have a vertical relationship with governmental actors, who serve as bridges to international cooperation programs, which are an important aid in accessing specialty cocoa markets. Producers with knowledge of bean production links have a greater horizontal relationship with neighbors, family members and other members of their community, an important aspect of community cohesion. Although knowledge has an impact on well-being, the knowledge of integrated management practices for cocoa cultivation in the departments is still deficient and limits the improvement of living conditions. Our results ratify the importance and need for training processes with a territorial approach. To increase the CKI and therefore the WBI, we recommend focusing training efforts on integrated programs in the nine links of the value chain, which will allow an improvement of the technological processes in the production and household systems, as well as the valuation of the importance of education in youth and training processes in the different rural livelihoods. Focusing training on post-harvest and transformation links leads to improved links with public and private institutions and encourages participation in the leadership of social-based organizations. Training strictly in productive links encourages the exchange of knowledge among neighbors and improves sensitivity to natural capital. The importance of rural extension processes is highlighted, which brings with it a challenge for academia in terms of the design of training processes focused on the needs of technicians and producers.

This new integral training in cocoa crop management should promote dialogue, interaction, and vertical and horizontal relationships between actors in the cocoa value chain. After our study, the following questions arise: How to mediate methodologically rural innovation processes between academics, technicians, producers, processors, traders, and other actors? How to make cocoa farmers aware of the need to improve the quality of the bean? How to return this effort to improve the quality of the bean through assets beyond the financial one? Given the advanced age of cocoa farmers, how can children and young people be involved in the empowerment of the cocoa value chain? Are bean transformation practices the alternative to dignifying cocoa work? If so, how can responsible consumption of 100% cocoa chocolate be promoted within short marketing circuits?

Funding Open access funding provided by Colombia Consortium.

Declarations

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Gustavo Adolfo Gutiérrez Garcia is a professor and researcher in the Agroecological Engineering program at the Universidad de la Amazonia. He belongs to the research group on Agroecosystems and Conservation in Amazonian Forests GAIA. He is currently a PhD student in Natural Sciences and Sustainable Development. He has accompanied research projects in the Orinoco, Amazon and Southern Andean regions of Colombia. He has done research mainly in rural sociology, especially in understanding the actions of cocoa producers and their empirical knowledge about cocoa cultivation in Colombia.

Isabel Gutiérrez-Montes is a Colombian Biologist (Universidad Nacional de Colombia), MSc. in Natural Resources (CATIE) and Ph.D. in Rural Sociology (Iowa State University). Isabel works in Mesoamerica and South America using qualitative research methods as a diagnostic and planning tool in landscape management, assessment of vulnerability, implementation of farmer field schools, and socioenvironmental educational programs. Worked as the dean of CATIE (Tropical Agricultural Research and Higher Education Center) graduate school. Academic coordinator of the Environmental Socioeconomics Masters Program, coordinator and leader of the Mesoamerican Agroenvironmental Program (MAP), and Director of the Development and Conservation Practice Academic Program (PAPDC) at CATIE. She has been a principal advisor in PhD thesis for 6 students and PhD thesis committees for 2 students. Major Professor of 50 Masters students and served as master's thesis committees of 35 students. She has published books, book chapters, technical and scientific articles in English and Spanish.

Juan Carlos Suárez Salazar is a professor and researcher at the Universidad de la Amazonia in Colombia. He is an Agroecological Engineer, with a master's degree in Tropical Agroforestry from CATIE, Costa Rica and a PhD in Biological Science from the National University of Colombia. He currently serves as vice rector of research at the Universidad de la Amazonia. He has experience in research activities, mainly in sustainable agricultural production systems, plant physiology and livelihoods.

Fernando Casanoves is an expert in statistics, with extensive experience in the development of analytical techniques for ecological and social data. He is Head of the Biometrics Unit at CATIE in Costa Rica. He is one of the main authors of the INFOSTAT statistical package. He is an undergraduate graduate of the Faculty of Agricultural Sciences of the National University of Córdoba, Argentina, with a Master's Degree in Biometry through the INTA-UBA Agreement and a PhD in Agricultural Sciences. He has oriented courses in statistics at different universities in Latin American countries.

David Ricardo Gutiérrez Suarez is an Agroecological Engineer with a Master's degree in Sustainable Production Systems from the Universidad de la Amazonia in Colombia. He has experience in research and rural development, mainly in the study of collective action in small farmer organizations and agroecological management of cocoa cultivation. He currently serves as academic coordinator of the Agroecological Engineering program at the Universidad de la Amazonia in San José del Guaviare, Colombia.

Héctor Eduardo Hernández-Núñez is an Agroecological Engineer with a Master's degree in Sustainable Production Systems from the Universidad de la Amazonia in Colombia and a PhD in Agricultural Sciences from the Universidad del Tolima, Colombia. He has coordinated rural development and peace building projects in different areas of Colombia. She has experience in research on livelihoods and welfare of rural households. She also has experience in research on aspects related to cocoa cultivation.

Cornelia Butler Flora is a Charles F. Curtiss Distinguished Professor of Agriculture and Sociology Emerita, Iowa State University and Research Professor Kansas State University, served 15 years as Director of the North Central Regional Center for Rural Development, a twelve-state research and extension institute. Previously she was holder of the Endowed Chair in Agricultural Systems at the University of Minnesota, head of the Sociology Department at Virginia Polytechnic Institute and State University, a University Distinguished Professor at Kansas State University, and a program officer for the Ford Foundation. She has taught in Spain, Peru, Argentina, and Uruguay. She is past president of the Rural Sociological Society, the Community Development Society, and the Society for Agriculture, Food and Human Her books include Baptism by Fire and Spirit: Pentecostalism in Colombia, Interactions Between Agroecosystems, Rural Communities, Rural Communities: Legacy and Change (5 editions), Rural Policies for the 1990s, Community Capacity and Resilience in Latin America and Sustainable Agriculture in Temperate Zones.

Nicole Sibelet for 36 years, Dr Nicole Sibelet, agronomist (Msc) and rural sociologist (PhD in sociology), has worked on the sociology of the farmers' innovation and the relations between the Society and the trees in particular in the agroforestry systems. She analyzes the stakeholders' perceptions and the local knowledge, the stakeholders' practices and strategies' in the changes of their systems face to the crises. Her research strongly contributes for recognizing the capacity of farmers to innovate in the face of local and global environmental risks. Nicole Sibelet occupies 30% of her time in training activities (teaching, organization of scholar terms, supervizing Master and PhD students and post-doc fellows).