Quality control of goji (fruits of *Lycium barbarum* L. and *L. chinense* Mill.): A value chain analysis perspective

ABSTRACT

Ethnopharmacological relevance: Goji (fruits of *Lycium barbarum* L. and *L. chinense* Mill., Solanaceae) have been used as a traditional food and medicine for hundreds of years in Asian countries and are now consumed globally. Quality of herbal medicines is critical for safe use and has been shown to be affected by value chains.

Aim of the study: Using a value chain (VC) framework, we aim at understanding the influence of different VC types on goji quality and revenue of stakeholders.

Materials and Methods: Participant observation and semi-structured interviews were conducted during five months of fieldwork in the main production areas in China with a total of 65 stakeholders. Quality of goji, behaviour and financial performance of stakeholders was documented and analysed for different VCs.

Results: Ten different types of VCs were identified. VCs with vertical integration and horizontal collaboration were found to have a more coherent quality control and better goji quality as well as improved stakeholders' financial performance. Vertical integration at different levels was found for independent farmer-based VCs, horizontal collaboration was found in the cooperative-based VCs. Full vertically integrated VCs were found in large-scale production.

Conclusions: Goji quality and stakeholders' revenues are linked with different types of VCs which mirror stakeholders' behaviour driven by target markets. Considering their positive influence on quality and revenues, well-developed vertically integrated value chains are likely to become more important in the near future.

Keywords: *Lycium*, goji, value chain, financial performance, stakeholders, quality control, traceability, herbal medicine product

1. Introduction

Humans rely on plants for food and medicine (Ekor, 2014; Gu and Pei, 2017; Heinrich, 2010; Knoess and Chinou, 2012; Leonti and Casu, 2013; Liu and Cheng, 2012; Qu et al., 2014). In the wake of globalization, traditional and local plant-derived foods are frequently turned into commodities such as food supplements or nutraceuticals. It is estimated that this is a market worth over US$150 billion with an annual increase in value of over 10% per year (Dillard and German, 2000; Hilton, 2017; Jennings et al., 2015; Shikov et al., 2017). Overall, traditional plant-derived foods and medicines are of increasing importance both, for health problems in peoples' daily lives globally and within the context of fast developing business networks and opportunities. However, the larger the market becomes, the more quality problems arise (Posadzki et al., 2013). Most herbal medicinal products are applied in the form of mixtures which consist of hundreds of compounds, which makes quality control notoriously difficult (ChP Commission, 2015; BP Commission, 2017; EDQMH, 2017).

Moreover, in many countries the regulations of such classic formulas continue to be loose (Cyranoski, 2017; Qiu, 2007). Regulations for botanical food supplements are generally less strict and good quality is even more of a concern (Shao, 2017). Quality control of plant-derived products is crucial for ascertaining safety and health benefits. However, are the present quality control methods sufficient? What needs to be understood about the processes from the initial agricultural production / collection to the final commercial products?

Many quality control methods have been developed for the authenticity, purity, and the analysis of active substances of botanical products. They mainly rely on morphology, phytochemical analysis, and molecular identification. The most common methods are chromatography-based quantitative and qualitative analyses of constituents. These include high performance liquid chromatography (HPLC), thin layer chromatography (TLC) or high performance thin layer chromatography (HPTLC), infrared spectrometry (IR), gas chromatography (GC) and capillary electrophoresis (CE). Mass spectrometry (MS) is often used to identify substances and chemometrics is applied to analyse relationships among samples (Donno et al., 2016; Guo et al., 2017; Kokotkiewicz et al., 2017; Liang et al., 2004; Maldini et al., 2016; Martinez-Frances et al., 2017; Reich et al., 2006; Wagner et al., 2011). Today, molecular identification, including DNA barcoding and DNA metabarcoding, are seen as fast developing and increasingly important tools for species authentication (Chen et al., 2010; Heinrich and Anagnostou, 2017; Jia et al., 2017; Raclariu et al., 2017; Xin et al., 2013; Zhang et al., 2001). Bioactivities are also measured and often applied together with metabolomic analyses (Donno et al., 2015; Liu et al., 2017; Walch et al., 2011). Considering the complexity of botanical products, profiles of active substances provide only limited chemical information with metabolomic approaches being better suited to depict this complexity. They were successfully used in research on understanding quality control parameters of botanical products such as coffee, camellia oil, goji, or *Rhodiola* species (Booker et al., 2016; de Moura Ribeiro et al., 2017; Heinrich, 2008; Kim et al., 2010; Pelkonen et al., 2012; Shi et al., 2018; Yao et al., 2018b).

Safety is an important attribute of good quality. While safety issues may arise due to inherent toxic constituents of a plant, they often are due to external contamination through, e.g., heavy metals, pesticides, microbes, mycotoxins, and sulphites. Fortunately, all these substances are detectable with suitable technologies (Fu et al., 2017; Kan et al., 2011; Posadzki et al., 2013; Rather et al., 2017; Sharma et al., 2017; Silins et al., 2014; Yang et al., 2018; Yang et al., 2017; Yu et al., 2017; Zhang et al., 2012). Accordingly, the current technologies allow for the evaluation of the metabolomic and biological properties, as well as the harmful ingredients of a botanical product. However, are these sufficient for ensuring the quality and safety of botanical products?

The concept of value chains, which provides a framework for describing links between producers and consumers focusing most notably on the socioeconomic benefits to producers (Booker et al., 2012) has in recent years been expanded to also include a basis for understanding the products' composition and thus their potential therapeutic benefits. Heinrich (2015) and Raclariu et al. (2017) mapped different quality control methods along production stages (source, manufacture, and retail), indicating that quality control is dynamic and may consist of various inspections along the value chain of herbal products. Such measures were also applied onto functional foods, neutraceuticals, spices and herbs (Sarkisyan et al., 2017; Shao, 2017; Székács et al., 2018). Obviously, an effective quality control of a botanical product consists of a systematic control of the whole supply chain or value chain, which, however, is often not recognised by stakeholders in the relevant industries.

Value chain analysis has originally been used to expound the value-adding activities of an organization, including the primary activities and support activities and in the context of evaluating the socio-economic implications of specific production system (Booker et al., 2012; Porter, 2008; Porter, 2001). The term supply chain has been used for all movements from the raw material to the final product across different parties, and thus comprises exhaustive flows of materials, funds, and information (Mentzer et al., 2001). Commonly, the two terms are used synonymously and value chain (the term used throughout this paper) highlights the socio-economic aspects of these trade networks (Ayers, 2010; Booker et al., 2012; Heinrich, 2015). A botanical product always transits several levels of stakeholders and organizations from cultivation to processing and distribution, before it reaches the final consumers (Székács et al., 2018).

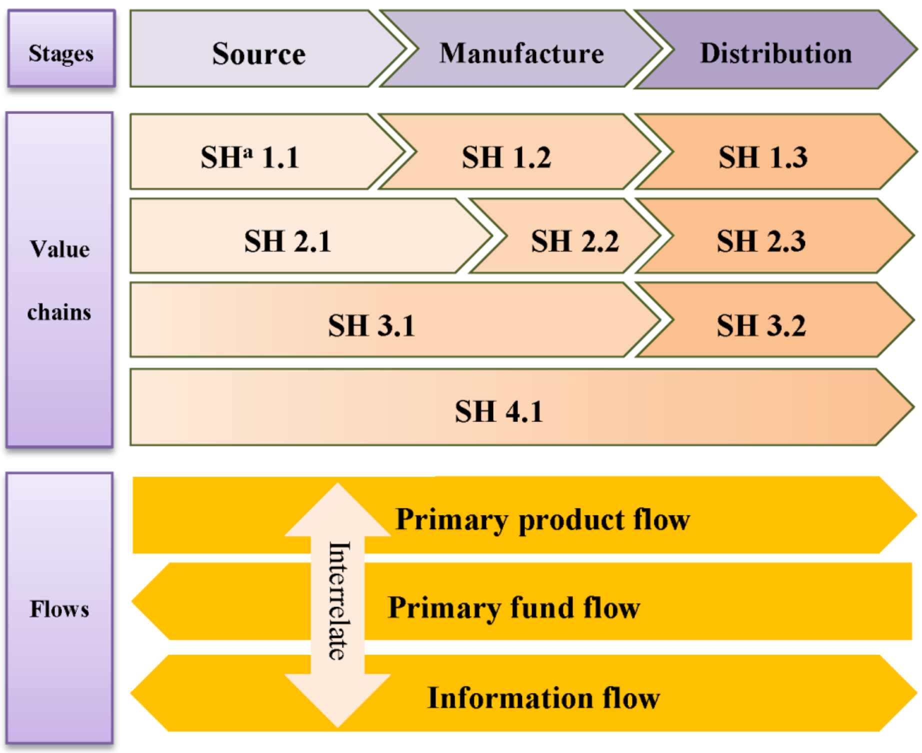

Fig. 1. Model of value chains and flow of materials in a value chain. [a] SH, stakeholder; adapted from Lambert et al. (1998); Raclariu et al. (2017); Székács et al. (2018).

Value chains of the same product can be diverse. As is shown in **Fig. 1**, a value chain may include different stakeholders, who contribute at different supply stages. It has been argued that vertically integrated value chain (VIVC) generally result in a better quality of products and can also enable a fair compensation of producers (Aung and Chang, 2014; Booker et al., 2016; Datta, 2017). In a value chain, three main flows are distinguished: 1) information flow is bidirectional among stakeholders; 2) primary product flow is unidirectional from primary producer to consumer; and 3) primary fund flow is unidirectional from consumer to primary producer. These flows interact and influence each other as has been shown in many case studies (Booker et al., 2016; Howieson et al., 2016; Székács et al., 2018). In the case of turmeric, for example, the producers' livelihoods were found to vary among value chains. Integrated value chains were found to result in higher quality products, which were shown to have an impact on chemical variability and quality of the product (Booker et al., 2014; Booker et al., 2016). To understand the influence of different value chains of botanical products on both the quality of the product and the income of the stakeholders, the three flows (product, information, and money) and their interrelatedness need to be analysed and understood.

In this study we analyse value chains of goji and their influence on stakeholders' financial performance as well as on the quality and safety of goji. Goji (fruits of *Lycium barbarum* L. and *L. chinense* Mill., Solanaceae) have been used as a traditional food and medicine for hundreds of years in Asian countries and have become increasingly popular as a healthy food globally (Qian et al., 2017; Yao et al., 2018a). Throughout the text we use the term goji inclusive for both species.

The earliest cultivation record dates from ca. 700 C.E.. Since the 1960s cultivars from Ningxia were spread over many regions of China for cultivation (Yao et al., 2018a; Yao et al., 2018b). China is the main production country and yields ca. 25 to 30 tons of dried goji annually (Cao and Wu, 2015; Xu, 2014). However, goji products are often of concern due to serious quality problems. For example, according to the US import alerts and EU RASFF notifications from 2009 to 2017, 208 batches of goji products were contaminated with pesticides or sulphur, of which some were even labelled as organic (FDA, 2017; RASFF, 2017). During our fieldwork in Chinese production areas in different climatic regions, we found diverse value chains interrelated to varying degrees with poor quality of goji, unfair sharing of revenues, and poor livelihoods of primary producers. Therefore the objectives of this research are:

What value chains exist for goji products? What information can be gained from a value chain analysis with regards to both best practices in supplying high quality materials and for identifying problems along the diverse value chains? What revenues gain the stakeholders in different value chains? How do financial mechanisms and quality control interrelate? What are effective approaches for quality control and a fair sharing of revenues?

2. Materials and methods

2.1. Fieldwork

Goji harvesting time stretches from June to October. Fieldwork was done during five months of harvesting periods 2014, 2015 and 2016 in Zhongning County of Ningxia, Ge'ermu City of Qinghai, Jinghe County of Xinjiang, and Julu County of Hebei, which are the main goji production areas and trading centres in China (**Fig. 2**). Participant observation and semi-structured interviews were conducted with experienced participants of the goji industry: 24 farmers, 7 harvesters, 5 village leaders, 5 processing firm leaders, 14 retailers, 8 middlemen, directors of two official goji management institutions (Goji Management Bureau of Jinghe in Xinjiang and the Ningxia Goji Institute). Farmers, harvesters, village leaders, and retailers were selected randomly in the core cultivation areas or trading centre of the regions visited; middlemen were visited as follows: the first middleman was introduced by our counterpart in Ningxia, and the others were introduced by the first middleman; the interviewed institutions were introduced by our counterpart in Ningxia. Questionnaires for different participants are shown in **S2**; in addition, we encouraged the interviewees to provide any information as they wanted. Interviews were recorded with a voice recorder and stored in the first author's home. Moreover, two authors attended a national goji industrial summit which was held in Ningxia on 20th August, 2015.

Fig. 2 Fieldwork sites in China. (Produced by R 3.4.3 with packages "maps" and "mapdata" (Brownrigg, 2016; Brownrigg et al., 2017; R Core Team, 2017))

2.2. Plant material

Goji (Fruits of *Lycium barbarum* L. and *L. chinense* Mill., Solanaceae) were collected during fieldwork in China. Samples were collected directly from the farmers, or offered by the institutions visited, or bought in Zhongning Goji Distribution Center, Julu Goji Yinhua Market, Xinjiang Jinghe Goji Market, Chengdu Hehuachi Chinese Herbal Medicine Market, and An'guo Chinese Herbal Medicine Market. Exported goji samples were bought in Switzerland, the UK, Germany, Poland, and Ireland. An authenticated reference standard sample of *L. barbarum* fruit was bought from the National Institute of Food and Drug Control of China, batch No. 121072-201410. Moreover, fruits with voucher specimens were collected in the National *Lycium* Germplasm Bank in Ningxia, Zhongning County of Ningxia, and Julu County of Hebei in July of 2016. Vouchers are deposited in the herbaria of the University of Zürich and ETH Zürich (Z+ZT), and the reference numbers are Z-000167501 to Z-000167535. All samples are listed in **S1**.

2.3. Pesticides and sulphur residue measurement

High sensitive pesticide detector cards (Oasis Biochem batch number: 00120161911, China) were used to measure organophosphorus and carbamate pesticides. Added 2 drops of washing solution to a plain fruit surface, and then rubbed with another fruit; transferred 1 drop of the solution to the white side of the test card; waited for 10 min; and then folded the test card and kept at 38 ℃ for 3 min; and then checked whether the card was blue. After measurement the samples were categorized in three groups: frequent, seldom, or rare contamination.

SO_2 test tubes (Oasis Biochem, batch number: 20160425, China) were used to measure SO_2 residue. Soaked 0.5 g dried goji in 10.0 ml water for 10 min, and then transferred 1.0 ml of solution into a SO_2 test tube and shaken, and 3 min later compared the test tube to the colorimetric card. The control was tested with pure water. Residues were presented as frequent, seldom, and rare according to the test results.

2.4. Value chain analysis

Firstly, procedures of goji production were compiled into an ordered flow sheet; secondly, stakeholders were added to corresponding procedures, so that stakeholders in the same chain were linked; thirdly, the labour cost and non-labour cost (mainly consists of materials, living costs, and outsourcing costs) of all stakeholders were calculated based on the interview data and cross-checked with information from goji industry, and then converted into Chinese Yuan/kg; fourthly, pesticides residue and sulphur residue of goji were linked with stakeholders. Finally, primary production behaviour was appended to corresponding stakeholders. The structure of value chains was mapped, and the financial performance, production behaviour, and quality of goji was analysed for each chain.

3. Results and discussion

3.1. Industrial structure and value chains

The earliest goji cultivation record was found in *Qianjin Yifang* published around C.E. 700 during the Tang Dynasty (Sun, 1998). Since the Ming Dynasty (around 1’300 C.E.), goji from Ningxia was listed in the tribute to the emperor, indicating that Ningxia yielded good quality goji (Cao and Wu, 2015). Since the 1960s, goji was introduced to Gansu, Xinjiang, Inner Mongolia, Qinghai, Tibet, and Hubei (Cao and Wu, 2015). Although Hebei was an independent historical production area with its unique germplasm, the superior cultivar from Ningxia was also introduced. Therefore, commercial goji of two species were cultivated in Hebei. With a long production history, the goji industry formed several mature value chains. Although there have been many new products, dried fruits are still the main consumable.

Typically, goji goes through six stages before it reaches its consumer: 1) Cultivation, including activities such as ploughing, planting, pruning, irrigating, fertilizing, pest and disease controlling, and harvesting; 2) Preliminary processing, or roughing, applied on the fresh fruit, and including surface treatment and preliminary drying of fresh fruits (moisture is reduced to ca. 17%), as well as removing impurities; 3) Procurement, i.e. trading of unprocessed goji produced in step 2; 4) Processing, including re-drying (moisture ≤ 13.0 %), removing impurities by winnowing, commercial grading, and packaging; 5) Wholesale, mainly to nonlocal markets; and 6) Retail. In each of these steps, different stakeholders can play a role, resulting in various forms of value chains (**Fig. 3**).

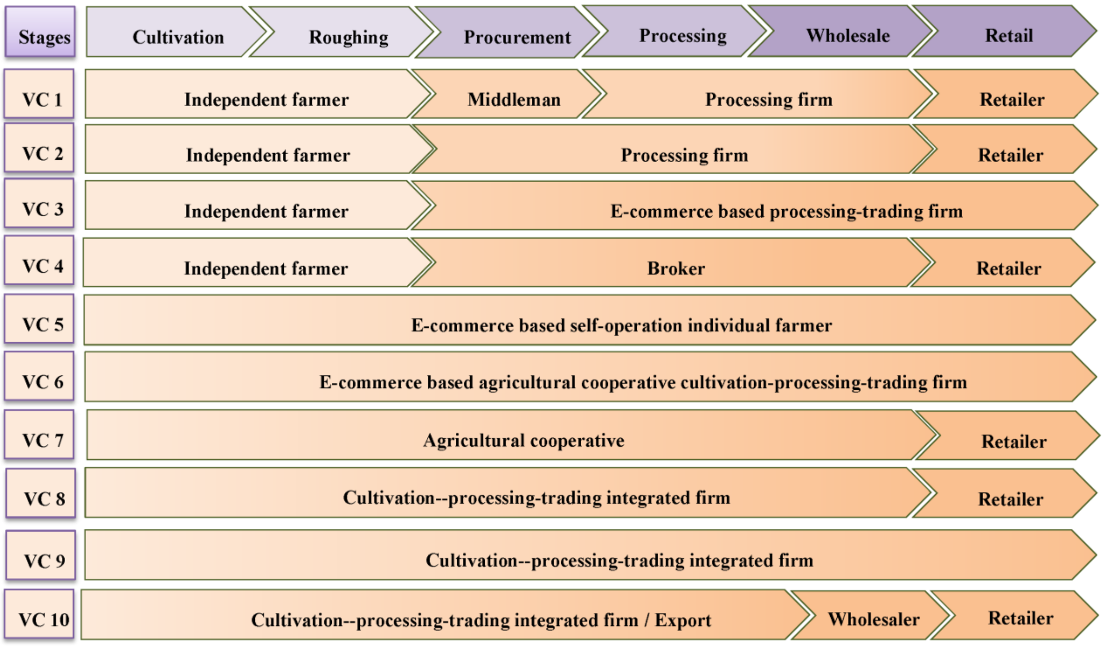

Fig. 3 Primary goji value chains (VCs) and the stakeholders involved. VCs 1, 2, 3, 4 are based on independent farmer; VCs 1, 2, 4, 7, 8 end with retailer; VCs 5, 6, and 9 are Full-VIVC; VC 10 is for exporting.

A key difference is found at the beginning of the VCs. 1) VCs 1 - 4 are based on independent farmers (with relatively small goji fields) offering their products to middlemen or other buyers; 2) VC 5 is run by individual farmers (with small goji fields); 3) VCs 6 - 7 start with farmers involved in agricultural cooperatives (with relative large fields); 4) VCs 8 - 10 are charged by the cultivation-processing-trading integrated firms (with large-scale goji plantations). Among these four types of VCs, VCs 6 - 7 show horizontal cooperation. It is found that products of the same origin may flow into different VCs, which promotes the diversification of VCs.

Products of the ten VCs will finally reach their consumers by four channels, which consist of farmers, retailers, shops of full-vertically integrated value chains, and external retailers. VCs 1, 2, 4, 7, and 8 end with a retailer and this kind of merging increases the complexity of goji VCs. E-commerce is also important in goji trading. While E-commerce has been involved in VCs 3, 5, 6, it is increasingly accepted by retailers of other VCs as well.

Additionally, vertical integrations at different levels are found in goji VCs. Some stakeholders (e.g., processing firm) take over the roles of others, inducing vertical integrations. For example, VCs 2, 3, 7, 8 are partial-VIVCs, while VCs 5, 6, 9, which are controlled by single stakeholders, are full-VIVCs.

As a traditional value chain, VC 1 has played an important role in the domestic goji market for decades. Independent farmers grow, harvest, and preliminarily process goji. Unprocessed goji is sold via middlemen to processing firms; goji is further processed and bulk packaged and sold to retailers, who sell the product to the consumers. VC 1 is especially prevalent for goji cultivated outside Ningxia, such as from Gansu, Qinghai, and Inner Mongolia. In Qinghai, for example, independent farmers often have large goji fields, but the local firms are not sufficient for processing and local consumption is limited. Therefore, middlemen sell the harvest to processing and trading centres in Ningxia. In average middlemen stay in Qinghai for five months every year, and are very important for this cross-province chain.

VC 2 and VC 3 are the results of the business expansion of processing firms. Due to the convenience of local trading centres, many processing firms are able to procure unprocessed goji directly from the farmers. As the middleman's participation leads to price increase, this upstream expansion strategy results in direct economic benefits for the processing firms. Processing firms' direct procurement is not only found in local markets, but also in nearby production areas, for instance, firms in Ningxia may procure goji in Gansu. Additionally, the development of E-commerce makes it possible for a processing firm to expand downstream. Just like VC 3, the processing-trading firm is able to play the roles up to the retailer.

In VC 4, the brokers act as a bridge between farmers and nonlocal retailers. Contracts are made between the brokers and retailers: brokers procure unprocessed goji, but outsource the processing, and finally send processed goji to the retailers; retailers will pay commission to the broker depending on the amount of goji.

VC 5 is a one-stop value chain conducted by self-operating individual farmers with relative large farms (ca. 1 to 2 hectares), who hire farm workers for production and processing. They sell their products via their own online shops. They may also sell their products to wholesalers.

VC 6 and VC 7 are agricultural cooperative-based value chains. Agricultural cooperatives are encouraged by the related governmental departments with beneficial policies. Farmers involved will get financial and technical support from the cooperatives, such as means of production, facilities for processing, and training in production technologies, and their products will be sold collectively, either to wholesalers, or consumers by online shops.

VC 8, VC 9, and VC10 are controlled by firms which control cultivation, processing and trading and are based on large-scale farms of over dozens of hectares. Their products are mainly sold to nonlocal retailers or consumers by their chain stores or online shops. In the case of the export chain VC 10, products are sold to foreign wholesalers who distribute to retailers such as supermarkets, groceries, and pharmacies.

3.2. Financial performance of stakeholders

Value of a product is created by the stakeholders' production activities. In different value chains, stakeholders always play different roles, and contribute different types of adding value by their labour inputs and non-labour inputs. **Table 1** shows the labour cost and non-labour cost along stages of the 10 main value chains.

Table 1 Labour cost (LC) and non-labour cost (NLC) of stages along goji value chains

Stage	Cultivation and roughing		Procurement		Processing and wholesale		Retail*	
Cost	LC	NLC	LC	NLC	LC	NLC	LC	NLC
VC 1	15.2 or 17.7	14.7 or 9.7	0.16	0.47	2.2	2	4.4 or 1.5	2 or 2.1
VC 2	15.2 or 17.7	14.7 or 9.7	0.16	0.47	2.2	2	4.4 or 1.5	2 or 2.1
VC 3	15.2 or 17.7	14.7 or 9.7	0.16	0.47	2.2	1.3	1.5	2.1
VC 4	15.2 or 17.7	14.7 or 9.7	0.65	0.1	0	4.8	4.4 or 1.5	2 or 2.1
VC 5	15.2 or 17.7	14.7 or 9.7	0	0	0	4.8	1.5	2.1
VC 6	15.2**	14.7	0	0	2.2	2	4.4 or 1.5	2 or 2.1
VC 7	15.2**	14.7	0	0	2.2	2	4.4 or 1.5	2 or 2.1

VC 8	15.2 or 20.8***	14.7 or 26.1	0	0	2.8	2.1	4.4 or 1.5	2 or 2.1
VC 9	15.2 or 20.8***	14.7 or 26.1	0	0	2.8	1.3	1.5	2.1
VC 10	20.8***	26.1	0	0	2.8	4.7	-	-

* For E-commerce, postage is borne by buyer; ** Policy: land rent free for 3 years; *** Policy: financial support for land rent and drying facility. Costs are presented as Chinese Yuan per kg of dried goji.

Most of the adding of value is achieved during the stage of cultivation and roughing. Non-labour cost at this stage consists of land cost, irrigation cost, fertilizer, and pesticides; labour cost includes work to care for the field, harvesting, and drying, and harvesting is the most costly part (ca. 45% of the whole costs), with an average of 13.5 Chinese Yuan (2.1 USD) / kg. However, the reward of people harvesting is not consistent with their labour input, and almost all of them are not satisfied with the working conditions. They need to pick fresh goji 15 hours per day, even during the hottest hours; with such intensive labour input, experienced harvesters can earn ca. 135 Chinese Yuan (21.3 USD) per day while the average wage is 90 Chinese Yuan (14.2 USD). Harvesting machines are commercially available. However, they are not widely applied as they only reduced labour input slightly but cause more impetus. For drying, farmers in VCs 1 to 5 have alternative methods: i) drying in the sun, which needs more labour input but saves costs; ii) or drying in the artificial drying room by outsourcing to agencies, which costs less labour but processing charges of 5 Chinese Yuan/kg. As a traditional approach, the former is often practiced by independent farmers; considering their large amount, the latter is suitable for VCs 6 to 10. Additionally, large-scale cultivation gains financial support from the government: for those with goji fields larger than 1.33 hectares, land use is for free during three years; also building of drying rooms can be done with the help of partial financial subsidies. For organic production chains, VCs 8, 9, and 10, costs are higher because of by increased cost of labour and organic fertilizer, and the cost for certification and management. Cultivation and roughing add most value to goji, but independent farmers obtain small margins only because of the risk of price fluctuation and their low bargaining power.

Procurement is a key process in VCs 1 to 3 and is driven by middlemen. Their costs include procuring and reselling labour, travelling cost, and transportation cost. As a linkage of bulk trading among different geographical sites, middlemen need a rather high capital turnover, ranging from 0.6 to 1.5 million Chinese Yuan. As the turnovers are not always smooth, credit operations are important to them. For credits, non-governmental organizations such as goji chambers of commerce are founded, which provide financial guarantees to their members. However, in other chains, the function of middlemen are omitted or replaced, e.g. by brokers in VC 4. Compared to the cost of middlemen, those of brokers are higher in labour input and lower in non-labour input. This may be due to the smaller amount of goji processed by brokers per day (ca. 100~200 kg per day vs. ca. 1000 kg per day by middlemen), which increases the average cost of labour; brokers are working locally, which leads to low travelling costs.

Processing and wholesale are also labour-intensive stages, which include colour-based separation, re-drying, hand selecting, size-based grading, and transportation. The operational cost of the processing and wholesale stage is 4.2 Chinese Yuan/ kg. In case of the direct selling chain (VC 3) the cost on transportation decreases; however, processing charge for outsourcing is 4.8 Chinese Yuan/ kg, as in VC 4 and VC 5; in the well-controlled chains (VCs 8, 9, and 10), cost for quality control increase.

Retail, mainly run by high-street or shopping mall stores or online shops, is the final step to reach the consumer. Physical stores are traditional, which can be chained or independent, and the additional cost is made up of rent, labour and packaging. Due to its low start-up cost and operational cost, online shops become increasingly popular. There is no restriction to location, and to set up a new online shop, 10 000 Chinese Yuan (1580 USD) is enough, which is much cheaper compared to a small physical store (at least 60 000 Chinese Yuan (9480 USD)). According to our internet investigation, much more goji is sold by taobao.com compared to physical stores. For example, on November 11th, 2017, during the online shopping festival, about 179 tons of goji were sold in one hour. The monthly sales volume of a common physical shop is about 450 kg, which is lower than that of an online shop (ca. 4200 kg). Online shops are favoured both by retailers and consumers because of their low costs and shopping convenience. The export chain of organic goji, VC 10, has higher cost on quality control, customs clearance and international transportation. Outside of China goji is typically sold in health food shops, Asian markets and pharmacies, as well as online shops. As in other value chain studies, differences in the retail price (**Table 1)** were found between the conventional goji and quality certified goji in domestic market, while the exported goji resulted in a much higher price.

The stakeholders will obtain profit by margin when they sell their products to the next stakeholder and the margin is impacted by the stakeholders' bargaining power and price fluctuation. As is summarized by Coff (1999), bargaining power is determined by the stakeholder's capacity of unified action, access to information, replacement cost, and exiting cost. Evaluated by these criteria, the large stakeholders have strong bargaining power. In VC 1 for example, independent farmers, especially those in rural areas, do not have reliable access to market information; while their rival, the middlemen, have direct contacts with the distribution centres; as a result, farmers are often disadvantaged. The price fluctuation of unprocessed goji during the last five years is shown in **Fig. 4**.

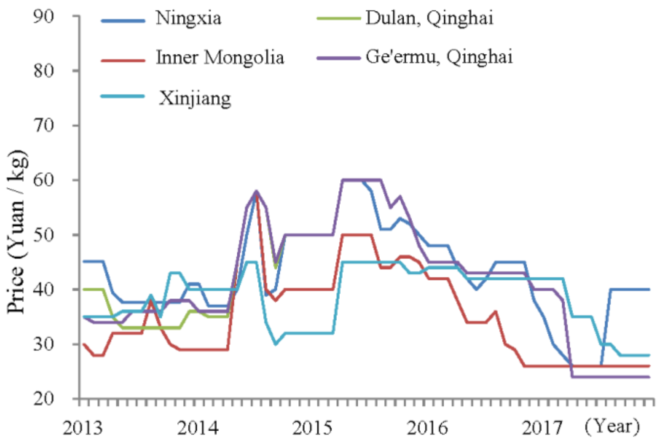

Fig. 4 Price fluctuation of unprocessed goji in local markets from 2013 to 2017. The average monthly price data were extracted from http://www.zyctd.com/.

The price of unprocessed goji ranges from 24 Chinese Yuan (3.8 USD) / kg to 60 Chinese Yuan (9.5 USD) / kg, and the coefficient of variation (CV) is between 14.26 % and 26.23%. The lowest cost is 27.4 Chinese Yuan (4.3 USD) /kg; thus, the price can be lower than the cost, which results in a deficit for the farmers. Although our interviewees may storage goji when the price is lower than they can accept, it is still a bet: the quality of goji will decrease during (prolonged) storage, and it is not certain that prices will rise soon. As a result, independent farmers in Ningxia started to turn goji into maize fields, which provides a more stable income. Alternatively, independent farmers are integrated in agricultural cooperatives, within which they obtain technological support, sale information, and stronger bargaining power. Once they were integrated in cooperatives, large-scaled production systems were developed. Large-scaled goji production is largely supported by governmental funding, such as reduced land rent and allowance for drying facilities. These economic conditions promote the larger scale production of goji in the upstream value chains, such as VCs 6 to 10.

The midstream (procurement, processing, and wholesale) which is traditionally charged by middlemen, processing firms, and trading firms may be prone to poor coordination of stakeholders. This results in the risk of discontinuity of material flow and financial return, which are vital for smallholders. For example, an overdue payment may lead to bankruptcy of a middleman. Thus, there is a trend towards vertical coordination in the midstream, such as VCs 2 to 10.

Although procurement price fluctuates drastically, the retail stage enjoys a stable price, offering a stable market to the stakeholders who are close to the consumers. This may stimulate processing firms and agricultural cooperatives to extend downstream to open retail businesses (VCs 3, 6, 9), or may even lead to the rising of self-operation farms (VC 5).

3.3. Quality evaluation of goji along value chains

The quality criteria of goji are published in different types of documents, such as pharmacopoeias and industrial standards (esp. of the food industry) (AQSIQ and SAC, 2014; BP Commission, 2017; CP Commission, 2015). Fruit weight and sugar contents are commonly used indices, while the contaminants such as pesticides residue, sulphur residue and heavy metals are often controlled for safety reasons. However, when being asked "what is good quality goji?" our interviewees always referred to the morphological and sensory traits of goji but never safety issues. Therefore, a quality investigation of goji from different value chains was exerted and the results are shown in **Table 2**.

Table 2 Quality evaluation of goji and possibility of hazard risks along different value chains

Value chain	Traceability	Certify	Control	Pesticide residue	Sulphur residue	Possibility of hazard risks		
						Cultivation	Drying	Processing
VC 1	No	No	Weak	Frequent	Frequent	Likely	Possible	Improbable
VC 2	No	No	Weak	Frequent	Frequent	Likely	Possible	Improbable
VC 3	No	No	Weak	Frequent	Frequent	Likely	Possible	Improbable
VC 4	No	No	Weak	Frequent	Frequent	Likely	Possible	Improbable
VC 5	Yes	No	Weak	Frequent	Seldom	Possible	Improbable	Improbable
VC 6	Yes	Maybe	Medium	Seldom	Seldom	Possible	Improbable	Improbable
VC 7	Yes	Maybe	Medium	Seldom	Seldom	Possible	Improbable	Improbable
VC 8	Yes	Yes	Strong	Rare	Rare	Improbable	Improbable	Improbable
VC 9	Yes	Yes	Strong	Rare	Rare	Improbable	Improbable	Improbable
VC 10	Yes	Yes	Strong	Rare	Rare	Improbable	Improbable	Improbable

As an effective quality control tool complied with legislation in food industries, traceability was applied to improve the safety of food and the confidence of consumer, as well as to connect producers and consumers (Aung and Chang, 2014; Dabbene et al., 2014; Regattieri et al., 2007). However, goji of the value chains including independent farmers, viz. VCs 1 to 4, have poor traceability. Since the independent farmers sell their goji in large quantities to other stakeholders, traceability becomes impossible. In other chains, where unprocessed goji is directly processed, traceability is feasible. With the increase of consumers' concerns on traceability and the development of information technology, a traceability system for goji has been available to the public by Quick Response (QR) Code since 2015. This QR code has also been encouraged by the government, for example, Zhongning County offers an allowance of 0.03 Chinese Yuan / piece. Since bulk goji loses traceability at the auction, but policy and consumers are in favour of it, value chains VCs 1 to 4 are inferior in this respect.

Certification of a product, such as organic food, increases consumer's confidence, especially in the health food market. Driven by the market, goji production is subject to certification. Perhaps the most attractive certification is the organic certification. However, in 2012 considering the complexity of goji production, Chinese Certification and Accreditation Administration (CNCA) discontinued organic certification of goji in China, and goji products in China were not permitted to be advertised as organic any longer. However, in order to meet the demands of foreign high quality markets, goji producers applied for certifications from organizations abroad, such as EU organic and HACCP (Hazard Analysis Critical Control Point). Practically, small stakeholders cannot afford these certifications. On the other hand, companies involved in VCs 8 to 10, who deal with large amounts of products for high quality markets, are always certified. For agricultural cooperatives, certifications are always not certified.

Formal legally binding regulations or self-regulations are considered to be essential for good quality (Booker and Heinrich, 2016; Booker et al., 2015). However, without a powerful regulatory authority, and weak self-regulation, the processes of the individual stakeholders are generally not well-regulated. Conventional production relies on chemical pesticides and biocides for pest and disease control, and chemicals will be applied 8 to 10 times during an annual production cycle. Independent farmers tend to apply excessive amounts of chemicals, which leads to problematic residues. Furthermore, a few farmers paid little attention to the safety interval before harvesting. These undesirable conditions have been caused by: poor education on how to use chemicals properly, and, while recommendations from pesticide sellers exist, no powerful regulatory authority controls the use of these substances. Also, pesticide residue detection is costly and, therefore, largely lacking in the value chains VCs 1 to 4. Compared to pesticides, sulphur is easier to detect and control, but overuse still exist in products from some value chains.

Safety hazards of goji samples are found to be linked to practices in cultivation, drying, and processing, and mainly existed in the independent farmers' value chains. During cultivation, goji is exposed to pesticides; when drying, goji may be exposed to pesticides again, as well as unhygienic conditions if dries by the road side; and while processing, low quality products may again be exposed to unhygienic conditions.

3.4. Relationship among behaviour, revenue, and quality

Goji is traditionally consumed as medicine and food. Nowadays, there is an increasing demand for high quality goji products. Therefore, goji products are involved in two types of markets: the conventional market and the high quality market. Since products for these two markets differ completely in their value chain, their behaviour-economic-quality was analysed comparatively (**Fig. 5**).

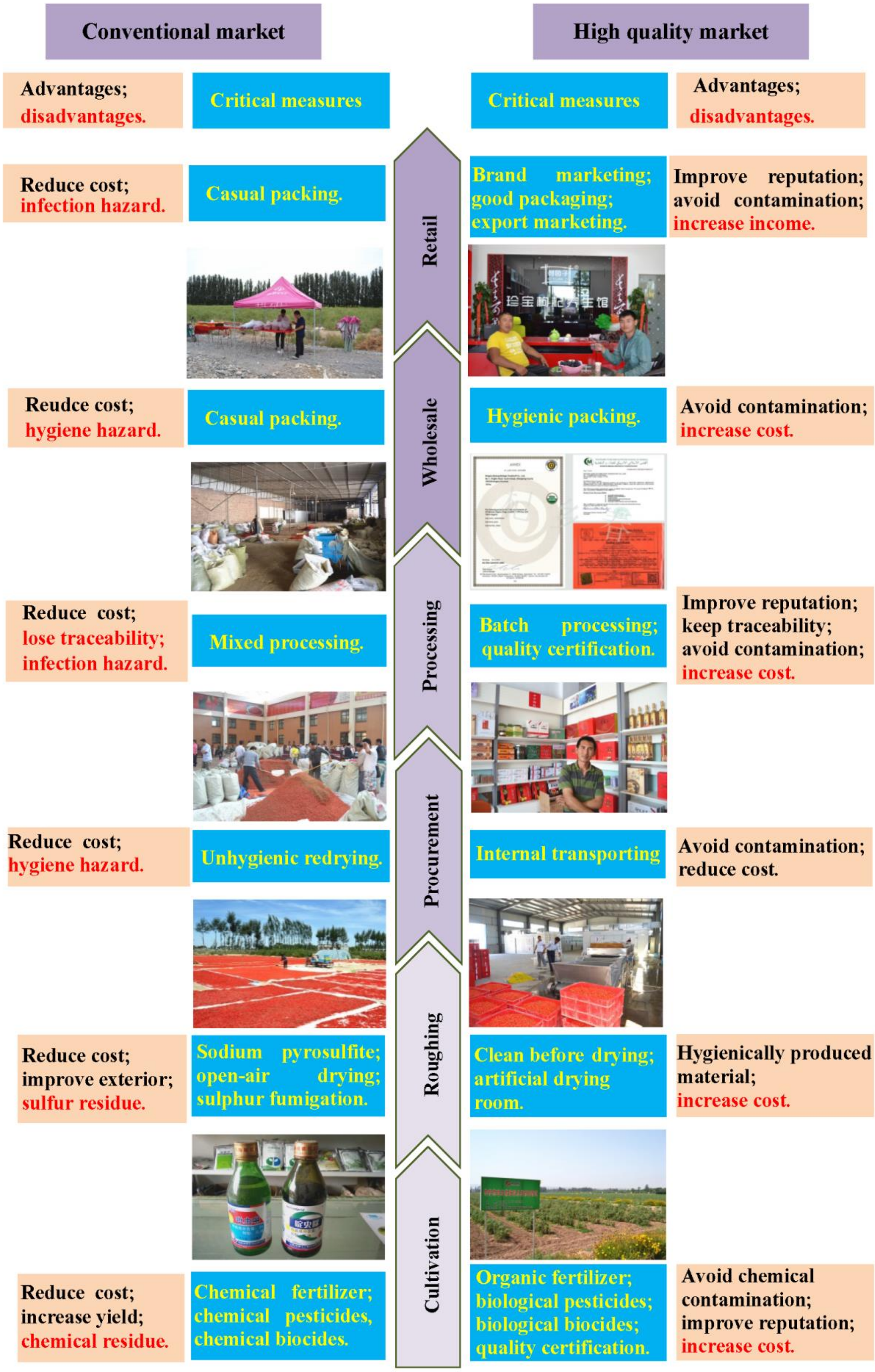

Fig. 5 Critical steps and their effects along value chains of conventional market and high quality market (Based on Booker and Heinrich (2016))

Stakeholders in both types of value chains want to increase profit, however, with different measures: in conventional market oriented value chains measures are taken to decrease costs and increase yield which causes quality loss; while in the high quality oriented chain products' quality and firms' reputation are improved, which increases the overall costs. High quality goji producers generally get higher revenues from the consumers, while stakeholders of the conventional market will get paid less. Therefore, the behaviour and revenue of stakeholders are linked with the quality and target market of products (**Fig. 6)**.

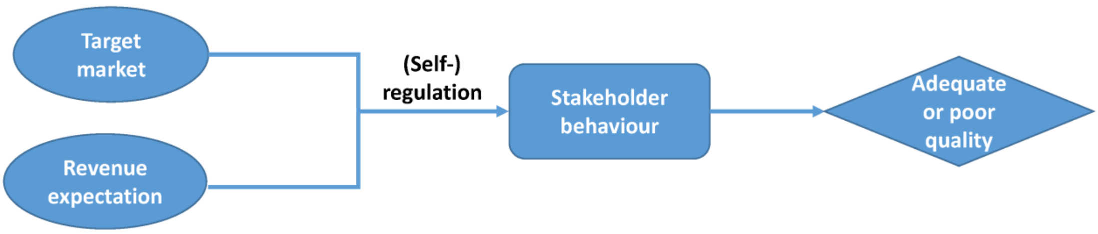

Fig. 6 The relationship among the target market, revenue expectation, behaviour, and quality

The intended target market has direct impact on stakeholders' revenue. According to our investigation, the price of goji in conventional market (40 ~ 60 Chinese Yuan (6.3 ~ 9.5 USD) /kg) is lower than that of the high quality market (such as green food and organic, 70 ~ 130 Chinese Yuan (11.0 ~20.5) /kg). The revenue expectation will induce the stakeholders' behaviour. Stakeholders for conventional market are inclined to reduce the production cost. Lower production cost results in behaviours which often pose quality risks, such as the application of pesticides. Consequently, the quality of goji is a direct consequence of the commercial decisions and the resulting production practices by the various stakeholders. Also, the quality of goji will further determine which market it could go. VCs 1 to 4 are examples of conventional market value chains. With the traditional target of getting high yields, chemicals and unhygienic measures are applied to goji without professional guidance. Consequently, quality problems are common and these goji could enter the conventional market with relative lower revenue. Products of VCs 5 to 7 can enter both markets, although they may not have quality certifications. Their production behaviours are mainly self-regulated, and reputation is built by reliable production and traceability. Value chains VCs 8 to 10 are for high quality markets, with the effective quality control during production and reliable quality certifications, these value chains produce goji of high quality, which brings high financial return to the stakeholders.

4. General discussion

In order to fulfil the increasing demand of the global market, the supply system of goji has recently undergone great changes, resulting in a diversity of value chains. In goji value chains we have demonstrated the emergence and development of vertical integration, horizontal collaboration, outsourcing, and E-commerce at different levels.

Vertical integration is induced by the business expansion of stakeholders. VCs 2 and 3 are the result of vertical integrations of processing firms, by taking over procurement (forward integration) and retail (backward integration). Of the ten value chains, VC 1 is without vertical integration, while VCs 2, 3, 4, 7, 8, 10 are partially integrated, and VCs 5, 6, 9 are full VIVCs. Vertical integration was reported to have many benefits, such as overcoming barriers among stakeholders, increasing financial profits, and decreasing price fluctuation (Görg and Kersting, 2014; Hanson, 2015; Shahidullah and Haque, 2010). These benefits are all found in goji value chains, especially in the full VIVCs (VCs 5, 6, 9). These VCs have been considered to be a competitive approach, with all the production stages being conducted by one stakeholder (Booker et al., 2016; Gereffi et al., 2005; Shahidullah and Haque, 2010). In the case of goji, farmers will get access to the market, as well as technological and financial support by joining vertically integrated value chains (Liu et al., 2015). Additionally, partial vertical integration attributes to a reliable traceability of its products.

Horizontal collaboration is shown as the alignment of stakeholders in charge of the same production stage, e.g. the agricultural cooperative. With a higher level of communication, trust, and common goals, they have higher revenue for the involved stakeholders, and chemicals used are better controlled (Martínez-Victoria et al., 2018;

Wollni and Zeller, 2007; Zhou et al., 2018). In the value chains VCs 6 and 7, farmers of agricultural cooperatives enjoy better economic status while the quality of goji is better controlled, too. Therefore, for individual farmers to join agricultural cooperatives could be a strategy for improving the quality of goji and stakeholders' revenues in VCs 1 to 4. Also the chamber of commerce founded by the processing and trading firms is an example of horizontal integration.

Outsourcing is found in several chains such as VCs 4 and 5. Expensive facilities, such as artificial drying rooms and grading machines, are not available for the smallholders and outsourcing allows the sharing of these facilities. Despite its function of resource allocation, outsourcing can bring disadvantages including quality problems (Dinu, 2015; Lahiri, 2016). Due to the existence of smallholders, the outsourcing would continue.

E-commerce offers a convenient and inexpensive approach for retailers to build direct access to consumers. While goji is produced in distinct areas of China, retail by e-commerce gets rid of spatial limitations. Since costs for running an online shop are low, they increase in number and are vertically integrated by processing firms. However, quality assurance practices in such chains are poorly understood and there is a need for certification of good practice in E-commerce.

5. Conclusions

Here we have demonstrated that goji's quality, stakeholders' behaviour and revenue are interrelated. Stakeholders' behaviour, which is driven by the target market, leads to quality differences. This in turn determines the financial return of stakeholders. Therefore, coordination of relationships in value chains could be a strategy for quality control of goji.

The diverse value chains are induced by vertical integrations and horizontal collaborations, while E-commerce promotes the vertical integration. Vertical integration and horizontal collaboration are beneficial to both quality of goji and revenue for stakeholders. Therefore, the relevant value chains are increasingly developed. Since well-developed VIVCs supply products with good traceability, reliable quality, and ensure adequate financial revenues of the stakeholders involved, in the future they are likely to become more important.

Quality control of herbal medicine products relies on quality regulation frameworks and quality inspections. Our study shows that quality is impacted by production process and financial performance, indicating that a robust value chain is the core of quality control. It also highlights the need for appropriate (self-) regulation and certification. With a value chain analysis including social-economic and quality factors, the present work emphasises the importance of the process control in herbal medicine products.

AUTHOR CONTRIBUTIONS

RY, CSW, and MH developed the concept for the study. RY and ZW drafted the paper. CSW and MH supervised the study. Fieldworks were conducted by RY with the critical help of ZW; plant materials were collected by RY and ZW; pesticides residue, and sulphur residue were measured by RY; ZW contributed critical financial data and behaviour information, and value chain analysis was carried out by RY and ZW. Data were analysed by RY and ZW. All authors revised the paper.

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