Cashew, from seed to market: a review

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REVIEW ARTICLE

Cashew, from seed to market: a review

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Abstract Cashew is a tropical tree native to South America. Cashew was introduced in Asia and Africa by European explorers in the sixteenth century. The world production of cashew raw nuts reached 4.27 million tons in 2011. Vietnam is the top producer of raw nuts, and India is the first processor and exporter of processed nuts. The cashew market is expected to remain strong due to the high growth of production in some areas such as West Africa. For instance, a 40 % production increase has been observed in Nigeria over the last 5 years. There is also an increasing exploitation of high-value by-products, particularly those made of cashew nut shell liquid. Cashew production is potentially a major value for smallholder farmers from emerging countries. Despite the relevance of cashew production on the international markets and the potential for boosting rural development and reducing poverty, a complete review on cashew is missing. Therefore, we review here the cashew production chain. Our main conclusions are as follows: (1) several management practices, processing methods, and uses of products and by-products are published; (2) however, there is still a lack of knowledge due to a scattered research framework lacking integrated research programs; (3) smallholder farmers face major constraints limiting the development of cashew sector locally, ranging from difficult access to good planting material and training to lack of investment for innovating processing facilities; (4) among them, women, that account for up to 95 % of the workforce in the sector, receive lower wages and are subject to worse working conditions.

Keywords *Anacardium occidentale* L. · Value chain · Cashew nut · Cashew processing · Smallholder farmers · Development

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1 Introduction

Cashew (*Anacardium occidentale* L.) is a tropical nut tree likely native of South America, with Central Brazil agreed to be the center of origin (Johnson 1973; Nair 2010). After the introduction of cashew crop to Asia and Africa during the explorations of European conquerors, mainly Portuguese, cashew has widely spread becoming a major export commodity crop for several countries. In 2011, about 4.7 million tons of raw nuts was produced worldwide, almost equally distributed between Asia and Africa, whereas almost 1.8 million tons over 2 million tons of cashew apples were produced in South America, namely, Brazil (FAO 2013a). The growing interest in cashew crop is shown by the evidence that cashew kernel, the main product cashew is cropped for, is a high-value luxury commodity with steadily growing production volumes and sales over the last 20 years (Azam-Ali and Judge 2001; FAO 2013a). Also, there are expectations that the market will remain strong for some time due the considerable potential to the cashew market for high-value by-products, such as cashew nut shell liquid, broken nuts, and cashew shell cake (Boillereau and Adam 2007). What is more, cashew has been mainly produced in emerging countries where it is both an agricultural commodity that significantly contributes to gross domestic product and export exchanges at the country level and an essential source for the livelihood of smallholder farmers that make up the majority of the producers and processors worldwide (Azam-Ali and Judge 2001; Fitzpatrick 2011). Therefore, the cashew industry plays an important role in the economic development of countries like Vietnam, India, Nigeria, Ivory Coast, and Ghana and should thus be considered a key contributor to the achievement of the United Nations Millennium Development Goals. Indeed, the cashew industry could be positively exploited in this sense for empowering smallholder farmers with a particular focus on women, creating revenues and employment opportunities, and promoting small- to medium-scale industrialization processes, especially in rural areas (Fig. 1).

Cashew production has been steadily increasing over recent years, which is more down to an increase in the cultivated area from 1,963,000 ha in 1992 to greater than 5,300,000 ha in 2011 (FAO 2013a) than an increase in productivity per hectare, which almost doubled from 475 to 805 kg/ha in the same reference period (FAO 2013a). The relatively limited improvement in productivity per hectare can be attributed to constraints in the improvement of cashew species through conventional breeding, for which there is still a limited understanding concerning vegetative propagation methods, including micro-propagation (Aliyu 2005). Additionally, map-based programs are still in their inception phase; thus, more research is needed to genetically characterize some agronomically valuable traits. Similarly, there is a wide variety of crop management techniques, processing methods, and equipment options that have only been partially tested and investigated, thus limiting their potential application. Therefore, in order to identify and highlight the major findings as well as the fields yet to be explored in the research on cashew crop, this review was undertaken by adopting a value chain approach. Following the methodology of this approach, the entire value chain of cashew crop was thoroughly reviewed by critically analyzing and summarizing peer-reviewed articles, conference proceedings, and reports by international organizations. The literature depicted a fragmented and dated framework that this review aims to update and organize.

2 Botanical description

Cashew (*A. occidentale* L.) is an evergreen perennial tree plant belonging to the family Anacardiaceae. This family is considered to encompass 60–74 genera consisting of 400–600 species, depending on the classification adopted (Bailey 1961; Brizicky 1962; Khosla et al. 1973; Mitchell and Mori 1987). Among the eight species in the genus *Anacardium*, only cashew (*occidentale*) is of economic value, due to its edible hypocarp and nutritious kernel.

Plant height varies considerably, ranging from 5 to 14 m. The canopy size also varies up to a width of 20 m. The root system is usually deep and widespread. The root distribution pattern depends on soil type, planting material and method, age, level of crop nutrition, and irrigation. Upon germination of the nut, the radicle develops rapidly into a tap root, which further produces laterals. As the lateral roots elongate, fibrous roots develop on the tap root. The early developed tap root system gradually takes up a complex structure of extensive roots with considerable lateral and vertical spread, with most

Fig. 1 **a** Farmer showing cashew fruit in the early stage of development in Zambia (©FAO/G. Thomas). **b** Women selecting cashew nuts for packing in Sri Lanka (©FAO/G. Bizzarri)

of the feeding roots residing in the surface layer of the soil. In shallow laterite soils, typical of tropical areas where cashew is probably native, cashew tree roots can extend up to 300 cm laterally around the tree and 100 cm vertically (Abdul Salam and Peter 2010). When propagated by transplantation, the level of development of root system determines the establishment of cashew planting material. Seedlings with good tap roots and a number of laterals better withstand transplantation shock and drought, whereas young seedlings with poorly developed root systems fail to establish during summer (Abdul Salam and Peter 2010).

The trunk is usually irregular and rather short, as the initial branches grow close to the ground. Leaves are green, elliptic to obovate, with smooth margins and sometimes a notched tip; they are arranged in a spiral pattern toward the end of the stem with a short stalk. Usually, there are 3 to 14 leaves on each terminal stem, which become fully mature after 20–25 days after emerging (Johnson 1973; Lim 2012; Ohler 1979). Flowers are gathered in a panicle which is up to 26 cm long and bears 5 to 11 laterals. The panicles predominantly constitute of male and hermaphrodite flowers in varying proportion. Both of them present a single large stamen and five to nine smaller ones. Overall, there may be 200 to 1,600 flowers per panicle (Aliyu and Awopetu 2008; Moncur and Wait 1986; Northwood 1966). Flowering occurs at the end of new shoots in the periphery of the tree canopy over a 30- to 60-day period during the vegetative flush that usually follows dry periods (Martin et al. 1997). In tropical climates, which are wet on and off throughout the year, flowering can occur at any time. Individual flowers are small, consisting of a small crown of five yellowish-green sepals and five white to reddish petals (Fig. 2.).

When open, flowers are receptive to pollen for several days. The stigma becomes immediately receptive, even though the release of pollen occurs later. This favors cross-pollination by insects, which largely predominates on self-pollination due to the sticky nature of the pollen (Aliyu and Awopetu 2008; Freitas and Paxton 1996; Northwood 1966). The fruit of the cashew tree consists of an accessory fruit and the true fruit itself. The former is an oval or, alternatively, pear-shaped hypocarpium deriving from the enlargement of the pedicel and the receptacle of the flower. It is known as the “cashew apple” and, when fully ripened, is a yellow and/or red structure 5 to 11 cm long. The latter is a kidney-shaped drupe that develops at the bottom of the apple. This is the first part to ripen on the cashew tree, followed by the cashew apple (Lim 2012; Johnson 1973; Varghese and Pundir 1964). Within this fruit, there is a single seed, the cashew nut, which is surrounded by a double shell containing anacardic acid, an allergenic phenolic compound (Hemshekhar et al. 2011; Lim 2012; Tyman and Morris 1967).

Fig. 2 Flowers of a cashew tree (©D. Lee)

Apart from the above-listed common features, there are two distinct morphological groups within the *A. occidentale* species that differ from one another in terms of size: the common type and the dwarf type. The former is bigger and generally more vigorous. Adult plants grow from 8 to 14 m in height and develop a crown span that reaches up to 20 m (Johnson 1973; Ohler 1979). They generally flower in their third year from planting, but the minimum age for stable production is usually 8 years and more commonly between 12 and 14. The individual production capacity varies considerably, with plants producing less than 1 kg up to more than 100 kg of nuts per year. Similarly, a nut’s weight can vary between 3 and 33 g, with the pseudo-fruit ranging from 20 to 500 g. The dwarf type generally reaches no more than 5 m in height, with a homogenous canopy 5–6.5 m wide. These plants have a notably shorter juvenile phase as they start flowering within 6 months so that they have a marketable production in their second or third year from planting (Barros 1995; Barros et al. 2002). These traits, for which dwarf clones were selected both in Brazil and India, significantly affect production performance; at the optimum planting density, within the reference period 1959–1995, the mean yield per hectare was found to be 1,200 kg for the dwarf type and 379 kg for the common type (Barros et al. 2002). Other characteristics that differentiate dwarf clones from common types include smaller and lighter green leaves, a smaller stem diameter, initial branches closer to the ground, smaller nuts, and larger peduncles (Barros 1995). The genomic basis of such divergence in plant phenotype is not yet fully understood. The global increase in cashew crop production, in fact, is probably partly based on genetic improvement programs based on map-based breeding (Azam-Ali and Judge 2001). These programs may be underdeveloped, due to the long generation time of the species and to its outcrossing nature, therefore hindering the possibility of obtaining homozygous lines (Cavalcanti and Wilkinson 2007). A clear example of the lack of clarity in the genetic background of cashew is the disagreement still persisting over the chromosome number and ploidy level of the species. Whereas there is a broad consensus that the crop is probably diploid, with a haploid count of $n=21$ (Aliyu and Awopetu 2007a), lower counts of $n=15$ and $n=12$ have been reported (Khosla et al. 1973;

Machado 1944). In order to overcome these issues, more attention is now being paid to genome-based analysis with the aim of identifying loci that control economically viable traits (Aliyu and Awopetu 2007b; Cavalcanti et al. 2007; Cavalcanti and Wilkinson 2007).

3 Origin and diffusion

A. occidentale is considered native of tropical America, notwithstanding the uncertainty in defining its natural distribution, due to its long association with man. Johnson (1973) suggested that it originated in the *restinga*, meaning the low vegetation found in the sandy soil along the coast of eastern and northeastern Brazil. The similarity between the form of cultivated *A. occidentale* and the native trees found in *restinga* vegetation is high (Johnson 1973). *A. occidentale* was also found to be an indigenous element of the savannahs of Colombia, Venezuela and the Guyanas, as well as occasionally a dominant feature of the savannah-like vegetation, also known as *cerrados*, of central and Amazonian Brazil (Nair 2010). Therefore, it is believed that *A. occidentale* originally evolved in the *cerrados* of Central Brazil and later spread in the *restingas* of the coast. However, recent findings shed further light on the origin of cashew. Archeological data from 47-million-year-old lake sediment in Germany provided evidence of distribution of cashew in Europe during the Tertiary period: such a discovery suggests a bio-geographic link between the American and European continents in terms of the distribution of genus *Anacardium* (Manchester et al. 2007). What is known for sure is the role of European explorers in spreading cashew throughout the world: it is well documented that the Portuguese discovered cashew in Brazil and thereafter introduced it to Mozambique and later India during the sixteenth and seventeenth centuries. After coming to the east coast of Africa in the second half of the sixteenth century, cashew then spread to the west coast and finally to the islands. Following its introduction into India, the plant was taken to Southeast Asia and later it spread to Australia and parts of North America such as Florida (Nair 2010).

4 Ecology

Cashew tree is a perennial, drought-resistant plant, originating from and mainly restricted to tropical and subtropical regions, with some exceptions found in temperate climates. It is cultivated in almost all tropical countries around the world, with the most intensive production regions lying between 15° south and north of the equator (Ohler 1979), where environmental conditions are often characterized by low soil fertility, low and/or erratic rainfall, and sometimes a considerable level of salinity (Bezerra et al. 2007). Good yield performances reaching 3 t/ha are obtained under high temperature, especially within the range 15–35 °C, with the optimum between 24 and 30 °C. However, the optimal temperature for seed germination is around 35 °C (Dedzoe et al. 2001). Usually, a dry period of 4 months or more is required for a reasonable yield due to the fact that flowering occurs after dry spells; however, flowering can occur at any time throughout the year in the case of an undefined dry season (Dedzoe et al. 2001). Nevertheless, an annual precipitation range of 1,000–2,000 mm is necessary for a good yield (Sys et al. 1993). In addition, the growth and development of the crop considerably depend on soil type and quality: though cashew grows on a wide range of soils, light- to medium-textured, deep, well-drained soils are generally the most suitable. With regard to this, Luvisols, Lixisols, and Acrisols have been reported to be highly suitable for cashew, being generally deep (>100–150 cm) and medium-textured (Dedzoe et al. 2001). Required base saturation levels should be above 35 %, whereas pH should range between 5.2 and 7. The optimum organic matter level is 1.4–3.0 % (Sys et al. 1993), even though in several areas devoted to cashew cultivation, such as in West Africa, organic matter content can be lower than 1 % (Dedzoe et al. 2001; Jones 1973). In such contexts, soil fertility is usually very low, since low organic matter content is often correlated with low nitrogen and available phosphorus in soils. However, such issues can be addressed by sound management practices, as cashew has been found to positively respond to nitrogen, phosphorus, and sulfur application (Grundon 1999; O'Farrell et al. 2010; Sawke et al. 1979). What may hinder cashew growth and development instead is salinity. This retards the germination process in precocious dwarf clones, with ECw 1.48 dS m^{-1} considered to be the threshold for irrigation water (Carneiro et al. 2002). Salinity was also shown to impair potassium metabolism depending on the substrate and duration of the stress (Viégas et al. 2001), as well as nitrogen metabolism, as it reduces the activity of enzymes involved in nitrate reduction (Viégas et al. 2004).

Although association with nitrogen-fixing bacteria has not been reported in cashew, arbuscular mychorrizal fungi biotrophically colonizing cashew were found to enhance plant growth by improving phosphorus nutrition. Shoot length, internode number and length, number of leaves, stem diameter, root length, and number were in fact found to significantly increase in the clone VRI-3, which is commonly used as cashew rootstock, and softwood for grafting was obtained earlier compared to the un-inoculated control (Ananthakrishnan et al. 2004; Lakshmipathy et al. 2004). However, there are still few studies exploring arbuscular mychorrizal fungi–cashew plant associations; therefore, further research should be undertaken in order to better understand the influence of environmental factors on fungal spore density, their distribution, establishment, and survival with the aim of developing large-scale inoculation programs.

5 Agronomic practices

A wide variety of agronomic practices applied in cultivating cashew are reported worldwide (Table 1). A review of them is provided here.

5.1 Propagation

There are two primary methods adopted to grow cashew: the former, and most widespread worldwide, is by placing seeds directly in the field. This is usually preferred over the latter, which consists of transplanting seedlings from nurseries. Seedlings have been reported to have a delicate root system to which transplanting may have a negative impact (Azam-Ali and Judge 2001). Apart from allowing the plant to naturally develop its root system (Ohler 1979), sowing is cheaper and quicker compared to other methods. Seeds are placed at a depth from about 5 to 10 cm, depending on soil texture (Azam-Ali and Judge 2001). Two or three seeds are sown together in order to avoid gaps in the plantation in case of seed failure (Ohler 1979). For seeds that have been stored for no longer than 5 to 6 months in gunny bags, and after been sun dried for 2 or 3 days, germination takes 15–20 days (Azam-Ali and Judge 2001). Transplanting is used because it provides the opportunity to select good seedlings to ensure uniformity while establishing the cashew orchard, which is not possible with sowing (Azam-Ali and Judge 2001). The age at the time of transplanting is critical to the success of seedling development; in Nigeria 2 to 3.5 months was recommended to transplant nursed cashew seedlings (Adenikinju et al. 1989), whereas in Ghana, high establishment success (>90 %) was observed after 1.5–2 months (Opoku-Ameyaw et al. 2007). When ready, seedlings are placed in the ground in a way to minimize damage to the root system. For example, in Cuba, baskets of uva grass are used and cut away when the seedling is transplanted. In Jamaica, seedlings are removed with a ball of soil and the top is cut back by one third before putting it into the ground (Azam-Ali and Judge 2001). In the case of rainfed plantations, whether they are sown or planted, cashew seedlings are placed in the ground during the rainy season, as seedlings and germinating seeds have to be securely rooted before soils dry out. In this sense, early planting is preferred as it gives more time for seedlings to develop before the onset of the dry season (Azam-Ali and Judge 2001).

Even though there are no studies investigating cashew production performance when propagated by layering, this propagation method is quite popular. Layering can take the form of either ground or air layering. In the former case, the tendency of the canopy to trail on the ground with the lowest branches spontaneously rooting has been exploited in India simply by covering such branches with soil and keeping it moist. However, such method was gradually abandoned, as the layers are not easily transplanted elsewhere, and they result in low trees of spreading habit (Azam-Ali and Judge 2001). Air layering instead was one of the most successful methods for vegetative propagation in cashew, providing the opportunity to obtain plantations from high yielding and uniform material. By contrast, it is rather laborious and only a few layers can be produced by each tree per year (80–120; Azam-Ali and Judge 2001).

Propagation by grafting was also extensively used as it permits the selection of desirable phenotypes. Rootstocks of varying age were tested, and a positive correlation between graft mortality and the age of the rootstock was found. However, it is the method that was proven to have the highest influence on grafting success: wedge grafting, in fact, showed to perform better than apical side veneer and side grafting, as it allowed the scion to sprout considerably (Mahunu et al. 2009). Along with these traditional grafting techniques, also inarching is reported for cashew (Azam-Ali and Judge 2001). Grafting was seen to be dependent on weather parameters: in particular, successful grafting was positively correlated to mean minimum temperature and the number of rainy days per month in India. Here, the monsoon period turned out to be the most suitable for softwood grafting with a success rate of more than 60 % (Swamy et al. 1990).

For a long time, there were no full-scale breeding programs applied to cashew, so the planting material was obtained simply by selecting either vegetative organs or seeds from the best performing plants when harvesting. From the 1970s onwards, a growing interest in exploring the genetic diversity of cashew opened up the way for germplasm acquisition programs, promoting exchanges between Africa, India, and South America (Aliyu and Awopetu 2007b). It was expected that introduction of genetic materials of different geographical origin, along with possible genetic introgression among materials that coexisted for a long time, would have resulted in variation in the available cashew genetic resources. Since then, several studies have appeared exploring the similarities and diversity in the genetic pool of cashew around the world, trying to identify parental lines and exploit heterosis with the aim of selecting economically valuable traits (Mneney et al. 2001).

5.2 Land preparation

Land preparation is a critical step for establishing a cashew plantation as cashew is very sensitive to competition with weeds as it grows in full light. The detrimental effects of weeds are higher during the early stage of development, as roots of weeds and seedlings are in the same layer of soil, thus competing for water and nutrients (Opoku-Ameyaw et al. 2012). In light to medium soils, pits are usually dug to a depth of 60 cm×60 cm×60 cm. In case of harder substrates, pits may be 1 m deep to compensate for the lesser depth of top soil. Pits are first exposed to direct sunlight, which help in removing termites and other harmful insects (FAO 1998) and are then filled with soil mixed with poultry manure, compost, and possibly phosphate about 2 weeks before planting. Such loose and fertile soil is favorable to germination (Azam-Ali and Judge 2001).

Density planting considerably varies: in Tanzania, 40 trees ha^{-1} was reported for large trees, as well as 120 trees ha^{-1} for

Table 1 Summary of the agronomic practices adopted worldwide in cashew cultivation: a brief description and the geographic reference are reported for each practice

Agronomic practices		Notes	Countries	References
Propagation	Sowing	Seed directly placed in the field at a depth depending on soil texture (5–10 cm); 2 or 3 seeds per hole	Worldwide	Ohler (1979), Azam-Ali and Judge (2001)
	Transplanting	Seedlings transplanted from nursery. Age: from 1.5 to 3.5 months	Nigeria, Ghana	Adenikinju et al. (1989), Opoku-Ameyaw et al. (2007)
		Seedlings moved by using basket of grass or by taking up balls of soil then partially removed	Cuba, Jamaica	Azam-Ali and Judge (2001)
	Ground layering	Lowest branches trailing on the ground covered with soil and kept moist	India	Azam-Ali and Judge (2001)
	Air layering	A strip of bark removed from a year-old branch; the exposed wood wrapped in a sheet until a callus is formed and develops roots	India, Sri Lanka	FAO (1998), Azam-Ali and Judge (2001)
	Grafting	Depending on age, method, and weather conditions. Several methods reported, including wedge grafting, side grafting, and inarching	Ghana, India	Swamy et al. (1990), Azam-Ali and Judge (2001), Mahunu et al. (2009)
Land preparation		Pits dug prior to sowing or transplanting depending on soil texture, exposed to sunlight to remove pests and then filled with soil mixed with manure. Density, 40–120 trees ha^{-1}; 156–175 trees ha^{-1}; 625 trees ha^{-1} (associated with thinning)	Tanzania, India, Indonesia	FAO (1998), Azam-Ali and Judge (2001) Martin et al. (1997) Abdul Salam and Peter (2010)
Weeding		Until tree canopies shade out the weeds, weeding is done around the tree trunks up to a radius of about 2 m. Manual slashing, glyphosate application, and intercropping are reported	Worldwide	Ohler (1979), Opoku-Ameyaw et al. (2011)
Intercropping		Extensively applied, especially in the establishment phase. Association with cassava, groundnuts, maize, yam, and sheanut	Tanzania, Ghana, India	Martin et al. (1997), Opoku-Ameyaw and Appiah (2000), Opoku-Ameyaw et al. (2011)
Fertilization		Nitrogen application reported to increase productivity in the vegetative growth stage. Phosphorous and sulfur also reported to positively affect yield. Better response reported for organic fertilizers (cow dung and poultry droppings) than for inorganic sources	Worldwide	Grundon (1999), Azam-Ali and Judge (2001), O'Farrell et al. (2010), Ipinmoroti et al. (2011)
Irrigation		Significant increase in yield reported in response to irrigation In rainfed regimes, soil and water conservation techniques are reported to enhance plant growth and yield	India	Oliveira et al. (2006), Rejani and Yadukumar (2010)
Pest control		Chemical control reported as the most commonly used method; biological control also applied but its viability has to be improved	Worldwide	Nair (2010), Mohapatra et al. (2007)
Pruning		Carried out both for promoting a uniform canopy and for controlling pest once a year, commonly after the seasonal fruiting	Worldwide	FAO (1998), Nathaniels et al. (2003), Asogwa et al. (2008)
Harvesting		Generally nuts are collected when they have dropped; for fresh fruit consumption and juice production, cashew apples are collected on the plant	Worldwide	Azam-Ali and Judge (2001), Asogwa et al. (2008)

smaller plants (Martin et al. 1997). In India, a planting density of 156–175 trees ha^{-1} was used, with similar values reported in Indonesia (FAO 1998). When the density is as high as 625 plants per hectare, achieved by using a 4×4-m spacing, it is then subject to subsequent thinning, as cashew tree production can be significantly reduced by such overcrowding (Abdul Salam and Peter 2010). In this case, tree yield is used as selection criterion which allows cashew growers to reduce the variance in cashew production between trees (Martin and Kasuga 1995). Apart from relieving tree competition, tree removal was found to be beneficial also by creating a less favorable micro-climate for diseases (Martin et al. 1997).

5.3 Weeding

As previously mentioned, weeding is a major issue, as weeds can prevent seedlings from developing. Hence, until tree canopies shade out the weeds, weeding is essential around the tree trunks up to a radius of about 2 m. Several methods have been used to control weeds: for a long time, manual slashing was the most widespread but has recently been turned down for other methods due to its short-lived effects (Ohler 1979). The use of herbicide glyphosate was found to be significantly more effective, since after 1 year, greener leaves were observed in treated cashew plants with respect to control plants, and the weed composition remaining was easier to control (Opoku-Ameyaw et al. 2012). Weeding cycles generally coincide with fertilizer applications (FAO 1998). In low rainfall areas, mulching has been used as weeding practice, which also contributes to moisture retention and moderation of soil temperature (FAO 1998). Even though its economic viability for this purpose is still to be proven (Opoku-Ameyaw et al. 2012), intercropping provides an environmentally sustainable practice for weeding.

5.4 Intercropping

Intercropping has been extensively applied to cashew crops, particularly in the establishment phase, in line with an age-long practice of tree cultivation in the tropics (Opoku-Ameyaw et al. 2011). The benefits of this practice are well documented and range from improving the food security of growers by varying their diet, providing revenues for livelihood, and better exploiting soil resources (Rodrigo et al. 2001). The performance of integrated systems depends on the choice of the food crop to be coupled with cashew; according to Ohler (1979), the use of early bearing low-growing food intercrops should be preferred, whereas tall intercrops like certain varieties of sorghum (*Sorghum bicolor* (L.) Moench) and millet should not be grown with cashew as they cast too much shade and negatively affect cashew seedling growth. However, an intercropping of cashew with citrus and coconut was reported with no yield data in the coastal and northern districts of Tanzania, with cassava, groundnuts, and maize being more widespread in other areas (Martin et al. 1997). Recent studies conducted in Ghana testing cashew intercropped with sorghum, maize, yam, and groundnut demonstrated a significantly improved growth of cashew seedlings when associated with maize and groundnut. Nevertheless, no significant increase in cashew yield was observed nor did the intercropping tests turn out to be profitable apart from in the case of maize and yam, which highlighted the need to conduct further research with the aim of producing guidelines for cashew growers (Opoku-Ameyaw et al. 2011). Interestingly, cashew was also used as an intercrop in sheanut stands in Ghana (Opoku-Ameyaw and Appiah 2000). Even though there were no data proving the effect of cashew on sheanut production, the association was proven successful in that, after the application of potash and superphosphate, both the girth and the canopy of cashew seedlings increased, thus producing a shading effect and enhancing weed control (Opoku-Ameyaw and Appiah 2000).

5.5 Fertilization

The response of cashew to fertilizer application has been proven in several studies (e.g. O'Farrell et al. 2010; Ghosh and Bose 1986; Grundon 1999). Particularly, the greatest effect of nitrogen application on increasing yield was observed when applied during the vegetative growth stage. Such timing, in fact, was shown to reduce late flowering and nut drop (O'Farrell et al. 2010). Whereas phosphorus and sulfur applications were proven to positively affect plant growth and nut production (Grundon 1999), the response to potassium application is still controversial (Grundon 1999; Sawke et al. 1979). An important factor to take into consideration while planning fertilizer application is the nutrient removal from the soil, due to fruit and pseudo-fruit harvesting. With regard to this, Panda (2013), assuming an annual average yield of 5–10 kg nuts/tree, recommends to apply 500 g N, 125 P_2O_5, and 125 K_2O per tree annually in two split doses. Other mixtures of inorganic fertilizers are also reported in literature, depending on the age and the growth stage of the plant. For example, Ghosh and Bose (1986) found that larger yields of cashew nuts were obtained with a combination of N, P_2O_5, and K_2O equivalent to 200, 75, and 100 g/plant/year, respectively. Subramanian et al. (1995), instead, reported the application of 250, 125, and 125 g/plant/year of N, P_2O_5, and K_2O, respectively, to be suitable for significantly increasing the yield of 15-year-old cashew plants. Concerning the type of fertilizer, there is experimental evidence that, when fertilized with inorganic NPK source (15:15:15) and organic fertilizers, cashew plants better respond to the latter in the form of cow dung and poultry dropping. These types of manure, in fact, contain other macro-and micro-nutrients like calcium and magnesium, which are not available from inorganic sources.

Moreover, manure slowly releases nitrogen thus limiting leaching and acidification and may improve soil structure and water content (Ipinmoroti et al. 2011).

5.6 Irrigation

Cashew crop is generally rainfed cultivated, but a significant increase in yield has been reported in response to irrigation. However, such response considerably varied depending on the clone, thus suggesting different interactions between genotypes and environmental conditions (Oliveira et al. 2006). Irrigation should be foreseen when water requirements reach their maximum, i.e., during the dry season, which often coincides with cashew flowering and nut development. Interestingly, in rainfed regimes, soil and water conservation techniques such as catch pits and reverse terraces were found to significantly enhance plant growth and nut yield by reducing runoff and nutrient leaching, as well as by increasing soil moisture on hilly land, thus opening up the opportunity to grow cashew on marginal land (Rejani and Yadukumar 2010).

5.7 Pest control

Among the factors significantly hindering cashew production are pests and diseases, the latter being by far the most important constraint. Pests include sap-sucking bugs, leaf-chewing caterpillars, beetles, aphids, scales, and mites. They cause considerable damage to foliage and fruits by determining the death of the floral-flushing shoots and the early abortion of young nuts, thus resulting in considerable loss of yield (Azam-Ali and Judge 2001). More than 190 species of insects and mites have been listed as pests occurring in different cashew-growing countries in the world (Nair 2010; for a sample of the most relevant, see Table 2), with the tea mosquito bug (*Helopeltis antonii*) being one of the most widespread, along with stem and root borers (Nair 2010). Apart from chemical control, which is by far the most commonly used method, biological control for the mosquito tea bug was also proved to be possible with options being found both in Asia and Africa, like *Erythmelus helopeltidis* parasitizing its eggs (Devasahayam and Nair 1986) and *Telenomus* sp. and *Chaetostricha minor* being its natural predators (Sundararaju 1993). However, the efficacy and the economic viability of the integrated pest management by biological control still need to be improved (Mohapatra et al. 2007), as well as the knowledge-sharing process with farmers, which has been found to be a major constraint in the implementation of this method (Nathaniels et al. 2003). Among diseases caused by pathogens, those brought by fungi are the most dangerous, particularly anthracnose caused by *Colletotrichum gloeosporioides*, black mold by *Pilgeriella anacardii*, and powdery mildew by *Oidium* sp. (Freire et al. 2002; for a sample of the most relevant, see Table 2). They can usually be controlled by fungicide applications.

5.8 Pruning

Pruning for tree training is commonly carried out both in Asia (FAO 1998) and Africa (Asogwa et al. 2008). Such practice is essential to promote the growth of a uniform canopy and avoid overcrowding, to which cashew plants are particularly sensitive. Plants are trained to a single stem where branches are allowed to grow about 0.75–1 m from ground level. Moreover, plants are usually kept at a height of 4–5 m by topping off the main stem, in order to reduce work required for orchard management. Pruning is also used as pest control practice, in that deformed branches due to infection by pests and diseases are removed to limit their spread (Nathaniels et al. 2003). Pruning should be carried out once a year and is conducted most commonly after the seasonal fruiting (Asogwa et al. 2008).

5.9 Harvesting

Cashew plants flower for 2 or 3 months and fruits mature about 2 months after the blooming. When the whole fruit is fully ripe, it falls to the ground and harvesting generally involves collecting nuts when they have dropped (Azam-Ali and Judge 2001). However, especially for fresh fruit consumption and juice production, where the apple is required to be fully mature, some farmers prefer collecting the cashew apples still on the plant to prevent pilferage and apple bursting (Asogwa et al. 2008). Harvesting is usually carried out manually from the ground, which is highly labor intensive and involves women and children. Alternatively, it is done by using a small basket or sack attached to a ring at the end of a long stick (Azam-Ali and Judge 2001). In order to ensure the quality of the product, nuts are dried out after separating them from the apple that, in turn, is usually processed within the first 24 h. Nuts are traditionally sundried for 2 or 3 days depending on weather and harvesting conditions, in order to bring down the moisture content from 25 to 7–8 % before processing (Asogwa et al. 2008; Mohod et al. 2010).

6 Cashew products and by-products: uses and processing

6.1 Products

Cashew has been cultivated essentially for food and medicine purposes by using the whole cashew fruit, i.e., the apple and the kernel. During the World War II, cashew gained further added value due to the exploitation of a major by-product, the

Table 2 List of major pests affecting cashew: species, common names, symptom, order, agent, and family are reported (Freire et al. 2002; Nair 2010)

Pest	Common name	Order	Family
Helopeltis antonii	Tea mosquito bug	Hemiptera	Miridae
Acrocerpos syngramma	Leaf miner	Lepidoptera	Gracillariidae
Lamida moncusalis Walker	Leaf and blossom webber	Lepidoptera	Pyralidae
Orthaga exvinacea Hamps	Leaf and blossom webber	Lepidoptera	Pyralidae
Plocaederus ferrugineus	Stem and root borer	Coleoptera	Cerambycidae
Thylocoptila paurosema M.	Apple and nut borer	Lepidoptera	Pyralidae
Nephopterix sp.	Apple and nut borer	Lepidoptera	Pyralidae
Selenothrips rubrocinctus	Foliage thrip	Thysanoptera	Thripidae
Retithrips syriacus	Foliage thrip	Thysanoptera	Thripidae
Disease	Symptom	Agent	Family
Anthracnose	Blossom blight, leaf spotting, fruit staining	Fungus	Glomelleraceae
Powdery mildew	Powdery growth leading to defoliation and failure of fruit	Fungus	Erysiphaceae
Phytophtora root rot	Chlorosis, wilting, leaf drop	Fungus	Pythiaceae
Angular leaf spot	Dark brown margin spots, defoliation of seedlings	Fungus	Mycosphaerellaceae

cashew nut shell liquid, which has then been extensively used for industrial applications (Azam-Ali and Judge 2001).

6.1.1 Cashew kernel

The kernel is the main product that cashew is cropped for. It has been estimated that about 60 % of cashew nut is consumed in the form of snacks, mostly roasted and salted. The remaining 40 % is instead used in confectionary and bakery products, often as a substitute for peanut and almond (Azam-Ali and Judge 2001). Apart from its pleasant flavor, the widespread consumption of cashew nut is due to its nutritional properties. Such properties are mainly linked to the high content in lipids, which is predominantly given by monounsaturated (MUFAs) and polyunsaturated fatty acids (PUFAs), and have been shown to lower low-density lipoprotein (LDL) cholesterol levels and coronary heart disease risks (Hu et al. 2001). Lipid content in cashew nut was found to range from 40 to 47 % (Gallina Toschi et al. 1993; Ryan et al. 2006). Investigations of the fatty acid profile revealed that MUFAs and PUFAs account for 79 % of total fatty acids, which approaches the 85 % composition for an ideal fat (Gallina Toschi et al. 1993; Venkatachalam and Sathe 2006). This feature is particularly relevant as such content can be attributed to oleic and linoleic acids, with the former being the most abundant MUFA and one of the most readily metabolized fatty acids and the latter the most abundant PUFA and precursor of prostaglandin, as well as an essential fatty acid (Gallina Toschi et al. 1993). The reduction of coronary heart diseases associated with nut consumption was also correlated with the presence of other bioactive compounds, such as tocopherols, squalene, and phytosterols (Kris-Etherton et al. 2001) that were found to be present in cashew nut, although to a lesser extent compared to pistachio and pine nuts (Ryan et al. 2006). Protein content was found to vary considerably, from 19 % (Venkatachalam and Sathe 2006) up to 36 % (Aremu et al. 2006; Pearson 1976). Carbohydrate content was seen to span from 1.4 % (Akinhanmi et al. 2008) to 26.8 % (Aremu et al. 2006), with 20–25 % being the most common values, depending on the level of crude fat and protein, in turn determined by cashew variety and environmental conditions (Akinhanmi et al. 2008). The analysis of the amino acid profile revealed glutamic acid, aspartic acid, and leucine being the most abundant (22.4–13.6, 5.6–10.2, and 6.2–8.0 %, respectively; Aremu et al. 2006, 2007; Venkatachalam and Sathe 2006). The same studies, in line with previous findings, confirmed high total amino acid content over crude protein (up to 76 % in Aremu et al. 2006), which makes cashew nut a good source of amino acids. The high quality of cashew nut amino acid supply is further confirmed by the high value of total essential amino acids, accounting for up to 47 % (Aremu et al. 2007). Such content, however, was found sufficient to meet adult requirements for lysine and threonine but not the requirements for infants (0–6 months) or children (up to 3 years) according to the joint FAO Expert Consultation (FAO 2013b); (Venkatachalam and Sathe 2006). Studies of mineral composition showed high content of potassium (up to 38 %; Aremu et al. 2006), followed by magnesium and calcium. Calcium content was found to be similar to phosphorus, which indicates that cashew nut is a good source of minerals for bone formation. Zinc and iron were found to be the least abundant (Akinhanmi et al. 2008; Aremu et al. 2006).

Cashew nut processing Cashew processing methods have evolved over the years, with the introduction of automation at some levels of the processing chain, as well as the diversification of operations across countries to meet environmental conditions and production capacities. The whole process concerns the extraction of the kernel from the shell. Difficulties in shelling cashew nuts are due to the irregular shape of the nut, the tough leathery outer shell, and the cashew nut shell liquid within the shell that must not be allowed to contaminate the nut during its removal nor compromise the health of the operator. This process has been traditionally done manually, which is still the case of small-scale processing firms, whereas it has converted into mechanized operations in large-scale processing plants. Regardless of the differences in the processing systems currently available, there are five major steps (Fig. 3), namely:

1. Preparation of the in-shell: this consists of a cleaning phase to remove any impurity, followed by a calibration grouping nuts of similar size that can be evenly processed afterwards. When not performed manually, these operations involve the use of extractor fans and rotating cylinders. Cashew nuts are then treated to increase the brittleness of the shell and loosening of the kernel from the shell. This is attained either by roasting, which would be preceded by soaking or conditioning of the nuts to increase their moisture content up to 15 to 25 % to prevent scorching or by steam cooking. The former option is widespread in Brazil in the form of oil bath roasting, which maximizes the recovery of the cashew nut shell liquid that is released at this stage but requires higher equipment costs. The latter option is performed in Africa and India. Nuts are treated in stationery or rotary steam cooker for 15–25 min at 0.75–5 kg cm^{-2} (Fitzpatrick 2011; Mohod et al. 2010).
2. Removal of the shell: this is performed either by cracking or manual or automatic cutting. Manual cutting coupled with steam cooking has been found to give the highest percentage of complete cut (up to 99 %). Manual cutting has for long been the traditional method for removing the shell by using a penknife, and it is still used in several small-scale processing units. However, this method is hazardous to the processor, since the cashew nut shell

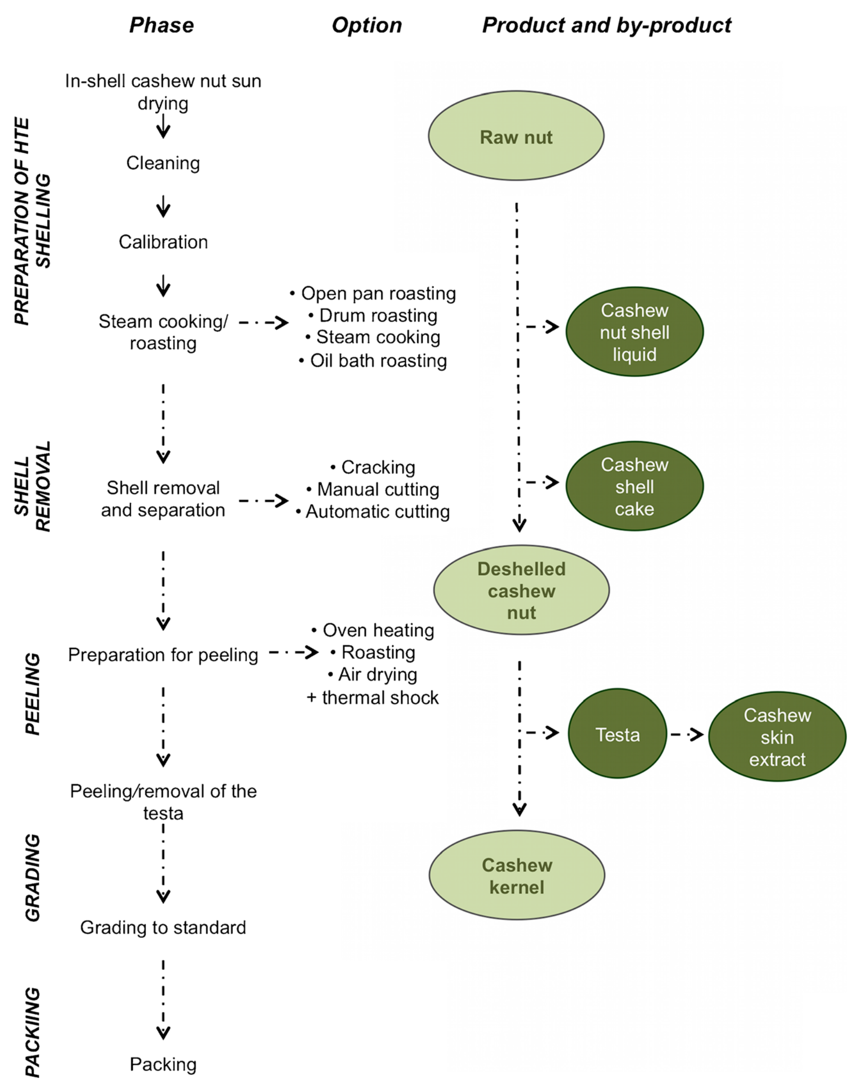

Fig. 3 Snapshot of cashew nut processing reporting: phases of the processing flow (*left column*), processing options reported in literature (*mid column*), and products and by-products resulting from processing steps (*right column*) (adapted from Asogwa et al. (2008) and Fitzpatrick (2011))

liquid oozes out of the shell onto the hands, thus constituting a health risk due to its caustic nature. Automatic cutting is performed in highly automated plants by using a shelling machine coupled with a mechanical conveyor.

3. Peeling: this is the step required to remove the testa that is made brittle and easy to peel by oven heating or roasting the nuts. In West Africa, the oven air drying is followed by a steam thermal shock performed in steam chambers. Peeling is then done manually or by using peeling machines with compressors, often coupled with manual finishing in order to increase the rate of fully peeled nuts (Fitzpatrick 2011).
4. Grading: kernels are graded by size and sorted by color. It is performed manually or automatically by machines such as drum or roller graders that select whole nuts that are commercially viable according to the international standards or broken pieces potentially suitable for domestic markets.
5. Packing: kernels are cleaned with aspirators usually available also in small processing firms and packed by vacuum packing and gas flushing in order to extend the shelf life of the processed nuts (Fitzpatrick 2011).

A study commissioned by the African Cashew initiative (Fitzpatrick 2011) that reports on a survey conducted in Vietnam, India, Brazil, and six African countries, namely, Benin, Burkina Faso, Togo, Ghana, Tanzania, and Mozambique portrayed deep differences among the processing systems in use in such countries, which are among the major cashew producers worldwide. Brazil, in fact, has mainly large factories based on mechanized and automated systems with high processing capacity. In India, small-scale firms mainly based on manual labor still coexist with new upgraded plants. Vietnam has been recently introducing new technologies, thus becoming highly competitive against African producers. The African framework, instead, revealed a certain uniformity in the methods applied for processing, but a diverse situation in terms of issues faced; whereas in East Africa, difficulty in finding labor has led to the purchase of machines for which there is no effective operational knowledge nor technical support, in West Africa, the industry is mainly based on manual labor-driven processing plants (Fitzpatrick 2011).

Analysis of the consumption pattern of unit operations in cashew nut processing depicts a varied situation. The energy intensity of the whole processing chain has been found to range from 0.21 to 3.80 MJ kg^{-1}, depending on the level of mechanization and the quantity of kernels being processed (Jekayinfa and Bamgboye 2006; Mohod et al. 2010). The same studies confirm that the most energy-demanding steps were the preparation of the in-shell and the drying of the kernels, which together accounted for up to 85 % of the total energy consumption. The low efficiencies of the machinery, along with low utilization of production capacity, were found to be the major limits to energy efficiency of the processing plants, regardless of the level of mechanization being implemented, the scale of the plant, and the option chosen for the pre-shelling preparation (Jekayinfa and Bamgboye 2006; Mohod et al. 2010).

6.1.2 Cashew apple

The cashew apple has several uses and applications; its consumption as processed is far more widespread than as a raw fruit, which is restricted to South America. Its diffusion is mainly due to its high content of vitamin C, since its juice is fivefold richer than citrus and fourfold richer than sweet orange (203.5 mg/100 ml of juice versus 33.7 and 54.7, respectively) (Akinwale 2000). The sugar content was observed to vary between 10 and 30 % (Azam-Ali and Judge 2001). Moreover, the apple contains a considerable level of minerals, mainly calcium and phosphorus. It also contains small proportions of tannins (up to 0.35 %) that confer an astringent flavor to the fruit (Nair 2010). Such a limitation is overcome either by blending the cashew juice with others, as mango, orange, and pineapple, that also serve to increase the content of vitamin C (Akinwale 2000) or by processing the fruit. With regard to this, different methods have been reported, such as steaming, boiling in a 2 % salt solution, or treating with gelatin (0.25–0.4 %) or pectin (0.35 %) (Nair 2010). Cashew apple residues remaining after juice extraction are nutritious since they contain 9 % protein, 4 % fat, 8 % crude fiber, and almost 10 % pectin. Their use to manufacture various products such as candies, jam, and drinks is widespread, as well as cattle feed after drying (Nair 2010). Other popular products obtained from cashew apple are cashew vinegar, cashew apple candy and jam, canned apple, cashew apple chutney, cashew pickles, and a wide variety of soft drinks. Cashew juice is also fermented to produce liquor in India, known as feni, having 40 % *v*/*v* alcohol content. Wine production from cashew apple was explored, to obtain a wine characterized by low alcohol content (7 % *v*/*v*) and high tannin content, resulting in an acidic taste that consumers did not appreciate (Mohanty et al. 2006). Due to its high sugar content, cashew apple juice has been found to be suitable as a source of reducing sugars for fermentative and enzymatic processes aimed at producing lactic acid, dextrane, and oligosaccharides (Honorato et al. 2007; Silveira et al. 2012), as well as for ethanol production (Pinheiro et al. 2008). Cashew apple has also been traditionally consumed for its medicinal properties as it is thought to heal diarrhea and prevent cholera (Azam-Ali and Judge 2001).

6.2 By-products

6.2.1 Cashew nut shell liquid

Cashew nut shell liquid is the most important by-product derived from cashew processing, due to its unique chemical properties that make it a good source for unsaturated long chain phenols (Tyman 1977; Quirino et al. 2014). The main applications of the cashew nut shell liquid are in the polymer industry, where it is used as a chemical compound in brake linings, paints, varnishes, and surface coatings (Kumar et al. 2002). Compared to conventional phenolic resins, cashew nut shell liquid-derived polymers offer greater flexibility resulting in products easier to process, as well as an increased resistance to weathering. Moreover, nut shell liquid-based resins provide notable resistance to the softening action of mineral oils and a high resistance to acids and alkalis. Other characteristics, such as termite and insect resistance, make these resins suitable for use in agriculture (Kumar et al. 2002), whereas the antimicrobial properties extend their uses to the medical field (Himejima and Kubo 1991). The wide applicability of cashew nut shell liquid, as well as the economic feasibility of its transformation for industrial purposes, suggests that this by-product is a promising bio-based compound that could potentially reduce the environmental impacts of the plastic and composite industry, while maintaining economic competitiveness (Quirino et al. 2014).

The outer shell waste represents about 70 % of the raw nut weight and contains up to 30–35 % of nut shell liquid (Das et al. 2004). There are several methods commonly used to extract the nut shell liquid, the choice of which influences the amount of oil that can be recovered, as well as its chemical composition. In East Africa, for instance, the traditional method introduced from India for removing the nut shell liquid is by roasting the nuts in drums or baths. Roasting in shallow pans over an open charcoal fire and collecting the expelled liquid results in yield of about 50 % of the total oil content (Das et al. 2004). When nuts are roasted in a bath at a temperature of 180 °C, the yield can be as high as 85–90 %. The hot oil process, based on a single layer of nuts passed for a few minutes in cashew nut shell liquid at 187–194 °C, coupled with the pre-conditioning of the nuts, also provides an extraction yield up to 90 %. Other methods have been reported using different solvents in solid–liquid and spray-type processes at lower temperatures (Das et al. 2004) and, more recently, relying on supercritical carbon dioxide (Patel et al. 2006). As previously mentioned, the composition of the cashew nut shell liquid considerably varies depending on the extraction method used (Table 3), with three major components being present in different percentages: anacardic acid, cardanol, and cardol (Tyman 1977) (Fig. 4).

The so-called natural nut shell liquid, i.e., cold, solvent extracted nut shell liquid, contains up to 90 % of anacardic acid to which the medical properties of the material are attributed; it has 10–20 % of cardol that is responsible for the vesicant activity of the liquid and contains only a small percentage of cardanol, if any (5 %). In the technical nut shell liquid, i.e., the heat-extracted nut shell liquid, the heating process leads to the decarboxylation of the anacardic acid to form cardanol, which is of particular interest for its polymerizable side chain and phenolic group. The typical composition is then more than 50 % cardanol, 10 % cardol, and 30 % other polymeric materials that are then removed by distilling the extract. This further increases the cardanol content up to 78 % (Das et al. 2004; Lubi and Thachil 2000).

Table 3 Physiochemical characteristics of cashew nut shell liquid, as reported by Akinhanmi et al. (2008). Parameters commonly used for analysis (*left column*) and range of values reported in literature (*right column*) are reported

Parameter	Value
Refractive index	1.686–1.693
Specific gravity	0.924–0.941
Viscosity (30 °C) (centripore)	41–56
Moisture (%)	3.9–6.7
Ash (%)	1.2–1.3
Saponification value (mg KOH/g)	47.6–58.1
Iodine value (mg/100 g)	215–235
Acid value (mg KOH/g)	12.1–15.4
Free fatty acid (mg KOH/g)	6.1–7.8

Normally, cashew nut shell liquid is refined by chemical treatment with hydrocarbon sulfates and sulfuric acid before industrial use to reduce sulfide, nitrogenous compounds, and minerals, which also affects the quality of the nut shell liquid. The treatment is generally performed by aqueous solutions of acids that reduce the vesicant activity of the liquid, but also treatments with amines were reported to reduce the content of cardol (Lubi and Thachil 2000).

6.2.2 Cashew skin extract

Cashew kernel is covered with a reddish-brown skin, or testa, that was reported to be rich in hydrolysable tannins, as well as in polyphenols, for which the content can be as high as 243 mg/g of cashew skin extract. Such compounds, particularly epicatechin, were found to possess significant antioxidant properties, as proved by the scavenging activity of the

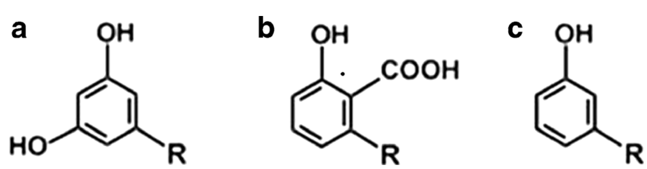

Fig. 4 General chemical structure of the main components of cashew nut shell liquid, namely, **a** cardol, **b** anacardic acid, and **c** cardanol

cashew skin extract when tested in antioxidant assays (Kamath and Rajini 2007). The same findings emerged from studies that aimed to test cashew skin extract treatment against dimethoate exposure. This widespread organophosphorous pesticide was reported to cause hyperglycemia and pancreatitis, the latter likely due to oxidative stress (Banerjee et al. 2001). Treatment with cashew skin extract proved to ameliorate and restore tissue antioxidant status in rat pancreases, as well as to confer normal glucose tolerance, thus indicating that cashew skin may be a promising source for natural antioxidants (Kamath et al. 2008).

6.2.3 Cashew shell cake

The residual shell cake after the removal of the nut shell liquid is currently used as fuel in cashew processing factories, as well as in-shell liquid extraction plants (Nair 2010): its calorific value was found to be 17.8 MJ/kg, higher than sawdust and cow dung (Mohod et al. 2008). However, its utilization is limited due to its loose form, which releases acidic fumes during combustion. Therefore, a mixture of cashew shell cake with other waste materials was tested and was proven to be successful with sawdust, cow dung, and wheat flour in different proportions. It provided briquetted fuel with good energy density ratio, low water absorption properties, shatter, and durability indices, indicating good resistance to shock and so increasing the ease of handling and transportation (Mohod et al. 2008). Therefore, the utilization of cashew shell cake as fuel is a promising option for enhancing the energetic self-reliance of cashew processing plants due to its wide availability and low cost.

6.2.4 Cashew bark

The bark of cashew trees has been traditionally used for its medical properties, which have been extensively reported in the literature. It is astringent and rich in tannins, which makes it widely applicable for healing hypertension, gastric disturbances, and inflammations (Mota et al. 1985). It was also proven to have bactericidal properties (Akinpelu 2001) and hypoglycemic activity that gives the possibility of using bark extract to treat diabetes mellitus (Alexander-Lindo et al. 2004). More recently, the cashew stem bark methanolic extract was proven to have anti-mutagenic effects, thus preventing DNA damage against potentially mutagenic compounds. However, such findings need to be investigated further to clarify the potential use of cashew bark extract in medicine (Barcelos et al. 2007).

6.3 Minor products

Apart from cashew kernel and the other major products and by-products above-listed, there are some minor products that constitute an added value for cashew production, often obtained from low-grade cashew kernels and fruits: (i) cashew kernel flour that is highly proteinaceous, often used as complement of wheat flour; (ii) cashew kernel oil that is edible and comparable to olive oil in terms of nutritional values; (iii) cashew kernel butter that is derived from the residual of the extraction of oil from the kernel, used as substitute of peanut butter; and (iv) cashew kernel milk, obtained from cashew broken kernels, also known as “baby bits” (Nair 2010).

7 International market and development

The world market for cashew is relatively new. Cashew, even though traditionally produced and consumed for centuries, started appearing on global markets toward the middle of the 1920s, with two major actors dominating the trade at that time: India, which was the sole exporter of cashew kernels, and the USA, being the only buyer (Harilal et al. 2006). The market has since considerably changed, including the appearance of other actors that created new poles on the cashew production and trade scenario.

In 2011, world production of cashew raw nuts reached 4.27 million tons (Fig. 5a), almost equally distributed between Asia and Africa (Fig. 5b), with Vietnam being the first producer accounting for about 30 % of the total production (Fig. 5a; FAO 2013a). The major role played by Asia is also confirmed by the presence of India, ranked third among the top five world producers. Vietnam and India, even though characterized by different trends, with the former experiencing a sharp rise in cashew production in the early 2000s and the second showing a more regular growing pattern, have recently shown similar trends due to their almost steady production volumes over the last 5 years (−1 and 9 %, respectively; FAO 2013a). This is different from the case of Brazil that, apart from accounting for the 99 % of cashew production of South America in 2011, has had an irregular trend over recent years due to cashew crop failures caused by periods of drought. The same data also show the importance of West Africa in the global scenario, with Nigeria and Ivory Coast accounting together for the 79 % of the production of this area in 2011, and display high growth rate of production volumes over the last 5 years (+27 and +40 %, respectively; FAO 2013a).

Historically, the cashew international market has been dominated by Eastern Africa and India. India, in particular, was the first country to set up a processing industry, mainly based on several small-scale firms relying on skilled labor. Indian domestic production has long been unable to meet the requirements of internal processing capacity, which consolidated the liaison with Eastern African countries as Mozambique, Kenya, and Tanzania as cashew suppliers (Azam-Ali and Judge 2001; Harilal et al. 2006). This trade declined in the

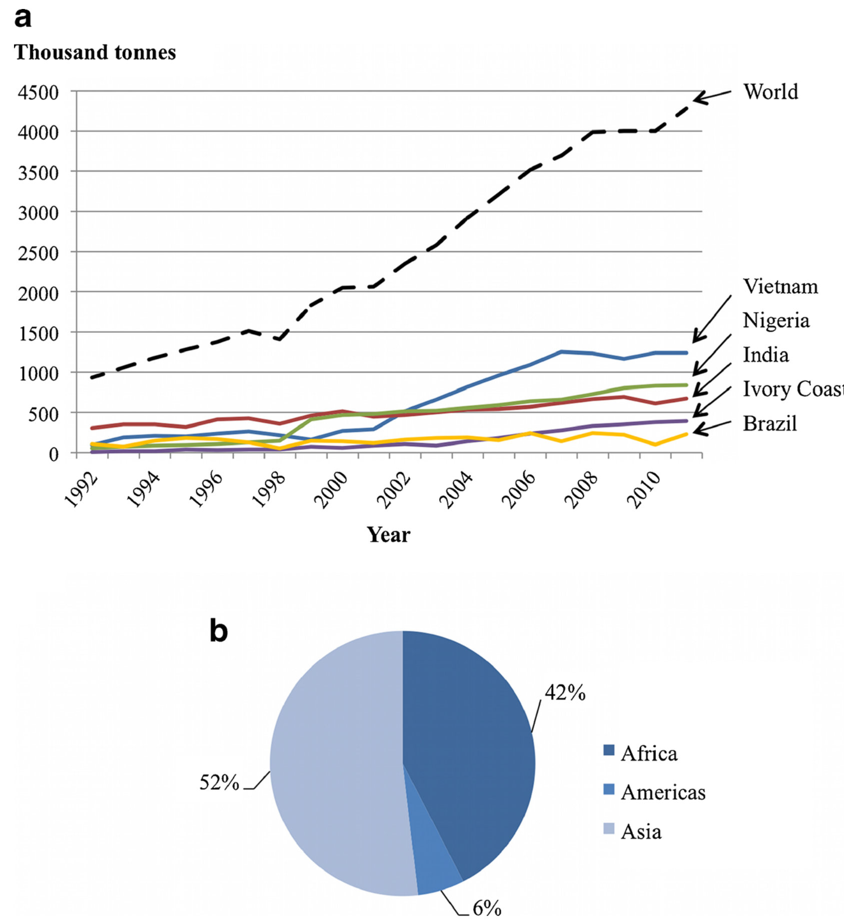

Fig. 5 **a** Cashew nut (with shell) world production over the time period 1992–2011 reporting the 2011 top five producers, namely, Vietnam, Nigeria, India, Ivory Coast, and Brazil, and the total world production. **b** Geographic distribution of cashew nut world production in 2011 (FAO 2013a)

early 1980s when East African production reached low levels. Exemplary is the case of Mozambique, once the leading world producer, then facing the civil war and the progressive decline of the sector, later only partially rejuvenated (Cramer 1999; Hanlon 2000). As a consequence, Indian markets opened to Southeast Asia, particularly Vietnam and Indonesia. With regard to this, it is important to note that in 2011, India was the world's primary importer of raw nuts, as well as the primary exporter of processed nuts, mainly to the USA and the European Union (Cashew Export Promotion Council of India 2013). Other markets—like Japan and Russia—have only opened up more recently (Harilal et al. 2006). While the relevance of Eastern Africa was declining, Brazil emerged as an important producer, encouraged by initial government incentives mainly aimed at boosting cashew production for both kernel and cashew nut shell liquid export to the USA (Azam-Ali and Judge 2001). Similarly to Brazil, West Africa has recently emerged on the international cashew market and is expected to further develop and consolidate its role in the global context, both in terms of production and export volumes. A report published by USAID (Boillereau and Adam 2007) highlighted that less than 10 % of the raw nuts produced in West Africa in 2006 were processed locally. This fact reveals the potential for developing the local processing industry to meet the internal demand for cashew derived products and for diversifying exports from this region. The current underdevelopment of cashew processing sector is partially attributable to the limited domestic consumption as, contrary to India and Vietnam, cashew is not a regular part of the diet in any country in Africa. Furthermore, the market for valuable cashew by-products such as cashew shell liquid is non-existent in Africa (Boillereau and Adam 2007). In addition, apart from few countries such as Nigeria, Benin, and Ivory Coast, in which production is mainly export-oriented and based on mechanized processing plants, the majority of firms in African countries are small to medium scale. Their limited production capacities, which can be largely attributed to the low level of technology in use, prevent such countries from producing enough to meet both qualitative and quantitative standards for international trade (Boillereau and Adam 2007).

Concerning cashew kernel prices on the international markets, the sector has shown a strong volatility over the last decade. This is due to the fact that market for cashew is not organized, meaning that there is no quotation for this product. Hence, available data correspond to real transactions whose significance, given the high rate of uncertainty, mainly lies in their trend more than in the data itself. Overall, the price of cashew kernels depends on several factors, among which the supply of raw nuts plays a major role, which has considerably fluctuated since 1999 (Horus Enterprises 2005). Focusing on recent years, the increase of cashew kernel price in 2007 and 2008 was due to poor crops both in Brazil and Vietnam, worsened by defaults of contracts and delays in shipment. Such an increase was then followed by a fall due to the reduced number of orders placed by importers, as influenced by the global economic crisis. However, since the second half of 2009, prices have been dramatically pushed up by an increase of labor cost in India, as well as by the strong competition between India and Vietnam to obtain raw nuts from Africa. In 2011, a record price was reached, peaking at 4.87 USD/lb for white whole cashew kernel, considered to be the benchmark grade. In 2011, the increase in prices halted, likely affected by the political crisis in Ivory Coast that made this major cashew supplier unattractive to foreign traders (CBI 2013). Since then, on the decreasing trend of cashew, price has had a significant impact the behavior of market players that prefer short-term buying, thus contributing to an increase in the volume of stocks available. Should the processing capacity of African producers significantly increase in the near future, competition with India and Vietnam for raw nuts will become stronger, probably leading again to an increase in prices. Along with the processing capacity, global demand of cashew products has played a crucial role in shaping cashew trade: the analysis of the international scenario revealed an annual increase in the demand for cashew kernel of about 9 % from 2001 to 2010, with a slight contraction in 2011 that persists to this day (CBI 2013). It is interesting to note that such an increase was mainly due to new rather than traditional consumers, such as the USA and Europe, whose consumption has been relatively stagnant (CBI 2013). Since the 1990s, China, Russia, Eastern Europe, and the Middle East have all emerged as significant consumers, due to a greater awareness of nutritional benefits of cashew nuts, as well as to the increased purchasing power of their citizens. Another factor that amplifies the uncertainty of the cashew market is the interdependency with other similar markets, namely, almond, pistachio, and macadamia, for which cashew is a substitute for to some extent (Horus Enterprises 2005; CBI 2013).

On the other hand, the high volatility of cashew kernel price on the international markets is mirrored by the high volatility of farm gate prices worldwide (Fig. 6), which are affected by several factors among which both quantity and quality of the harvest are the most important. This, in turn, is the result of different, often unpredictable driving forces, such as weather conditions and sociopolitical stability, which may also result in high variability in both inter- and intra-geographic areas. As an example, the above-mentioned political unrest in Ivory Coast that started at the end of 2010 and reached its peak in early 2011 likely contributed to the fall of cashew producer price to almost 410 USD/t against the average world price that year estimated around 1,390 USD/t (FAO 2013c).

7.1 Implications for smallholder farmers

As it may be noted from the literature reported in this review, cashew crop plays a significant role in the economy of some emerging regions, with cashew kernel being considered a high-value agricultural commodity. Interestingly, it shows an atypical trend, in that international markets are expanding rather than contracting (Azam-Ali and Judge 2001; Boillereau and Adam 2007; Harilal et al. 2006). Such a pattern could be positively exploited by promoting the sector within the framework of strategies that aim to reduce poverty, based on increasing and diversifying production and export. This is particularly true in light of the fact that, apart from few exceptions as Brazil, whose cashew industry is based on large-scale mechanized factories, the vast majority of producers and processors worldwide are small or medium scale, with smallholder farmers and processors playing a major role (Azam-Ali and Judge 2001; Mole 2000). However, their production capacities, on which their livelihood closely depends, are severely hindered by several constraints that, though context specific, are often common to many of them regardless of their country. For example, the lack of strategic planning in the inception phase has resulted in the development of scattered small-scale activities rather than integrated systems (Fitzpatrick 2011). Moreover, the lack of good planting material due to the absence of proper breeding programs, coupled with poor knowledge of pest control, soil husbandry, and agronomic practices, has widely compromised the production phase, resulting in generally poor yield. Such issues, whose effects have been sometimes worsened by adverse weather conditions, have for long not been compensated for by extension services, which have often been found to be inefficient and responsible for inadequate farmer training (Martin et al. 1997; Nathaniels et al. 2003). The scarcity of investments in the cashew industry, especially in contexts considered unattractive by foreign investors such as many African countries, has also prevented the sector from innovating at an adequate rate to keep pace with fast-changing markets (Fitzpatrick 2011). Recently, this trend has been counteracted, as demonstrated by the growing interest of multinational corporations in developing new entry markets, such as West Africa (Boillereau and Adam 2007). However, the lack of knowledge and support services has limited the positive impact of the introduction of technologies in processing plants, especially in contexts where there is a scarcity of available skilled labor, like East Africa (Fitzpatrick 2011). This has resulted in the usage of obsolete plants, often subject to water and power supply problems, significantly impacting both quantity and quality of cashew products. The low quality of cashew raw nuts and kernels in turn negatively affects farm gate prices and

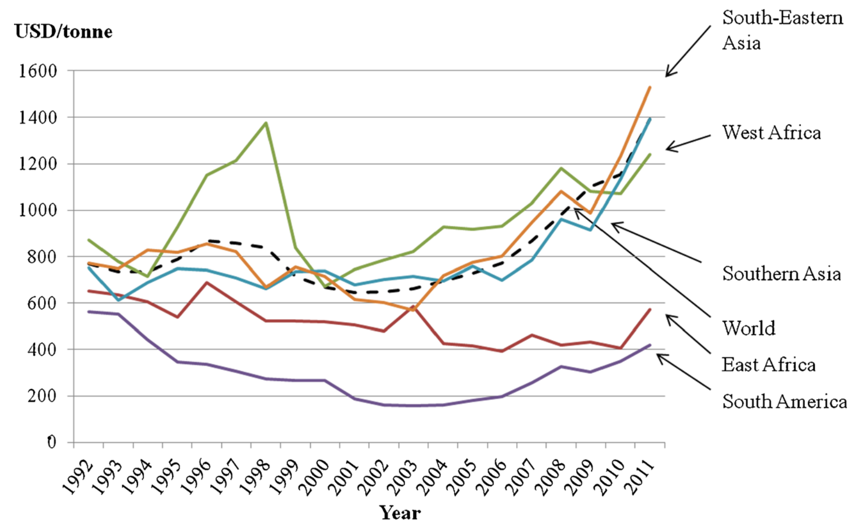

Fig. 6 Farm gate prices for cashew nuts (with shell) reported for the most important producers grouped in geographic areas with respect to the world average (FAO 2013c)

reduces the profitability of the activities conducted by producers and processors. In the African framework, the above-mentioned constraints are further exacerbated by inefficient distribution channels, resulting in high transport and packaging costs that, along with the suboptimal sales and consumption of broken nuts, limit the internal demand of cashew products (Boillereau and Adam 2007).

While the scenario of cashew producers is becoming more sophisticated with new actors coming up and competing with each other in the south, market share has consolidated among a few retailers and importers in the north. These retailers and importers can capture considerable value by providing secondary stages of processing, such as roasting, salting, and flavor addition. The location of value-addition and the buyer-driven nature of the cashew nut supply chain have negative implications for the wages and working conditions of workers in developing countries. This relatively small group of retailers and importers holds significant power in determining both price and quality of cashew products. They also indirectly determine labor conditions for suppliers and producers that in turn transfer the burden of competition to workers (Boillereau and Adam 2007). A survey conducted in India and Mozambique revealed the trade unions were weak in promoting workers' rights and therefore depicted an imbalanced relationship between workers and employers (Kanji 2004). Moreover, the increased competition on the international markets, leading to the liberalization of the cashew sector, has been found to push an increasing number of employees into becoming "informal" workers, with poor wages and health-threatening working conditions. Such a trend makes the quantification of workers engaged in cashew industry particularly difficult. This is due to the fact that, apart from employing informal laborers, small-scale industries are frequently neither even registered nor surveyed. When data are available, a clear trend emerges in the workforce composition. A notable share of the labor in the cashew sector worldwide is made up of women, who undertake various tasks along the value chain (Kanji 2004). Quantifying women laborers is a more difficult task than for men, as they usually accept more insecure working conditions for lower wages. This is partly due to the more limited choices they face and partly due to different societal expectations of what is acceptable for women and men. In the late 1970s, women were reported to make up half the workforce in Mozambique that, at the time, was one of the main cashew producers in the world (Azam-Ali and Judge 2001). Figures from India are even more explicative in this sense, as in the state of Kerala, that has the largest processing capacity in the country women were found to be the 95 % of the 500,000 workers surveyed in the 1990s (Nayar 1995). Such data was later confirmed by Kanji (2004) reporting about 400,000 women workers in the cashew industry in the same area. Despite their relevance in the sector, women are often unprotected by labor legislation, resulting in inequalities such as lower wages, exclusion from technology application, less bargaining power, and worse work environments, sometimes to the point of affecting their reproductive health (Kanji 2004). However, small-scale projects relying on the cooperation of governments, private sector, and nongovernmental organizations have had a positive impact on employment and labor conditions, which highlights the need for joint actions to support smallholders and, among them, the most vulnerable groups (Kanji 2004).

8 Conclusions

Cashew is a crop of major interest in the global scenario, which has been expanding in international markets over recent decades. Interestingly, among the main producers of cashew, there are emerging countries whose economy significantly relies on the cashew industry. Even though the industry varies significantly between countries in Asia, Africa, and Latin America, these countries are similar, since both production and processing are generally carried out by smallholder farmers that constitute the core of the cashew sector. In light of this, cashew is to be considered a key crop that could potentially enhance the development of local communities by supporting their livelihood and by empowering the most vulnerable groups involved in cashew production.

This review of the state of the art of cashew productive chain, which took into consideration the entire production system from "seed to table," depicted a scattered research framework for which a wide range of studies does exist, albeit generally applied to specific local contexts. This fact, as well as making a critical review difficult due to the different and not always well-explained backgrounds, reveals the absence of systematic information exchanges for comparative analysis that can share knowledge about this crop. Such shortcomings call for academic institutions and research bodies to collaborate on integrated research programs, where genetic breeding projects should be of central importance.

The present review also critically analyzed and summarized the plethora of agricultural practices, processing methods, and uses of products and by-products derived from cashew. This highlighted the major constraints limiting the development of the sector, with a particular emphasis on those affecting smallholder farmers and processors. In particular, farmers have difficult access to good planting material and training, resulting in a scarce knowledge on soil management, agronomic practices, and pest control and which in turn often leads to poor yield. Extension services that should address the main issues encountered by farmers have often been found to be absent or inefficient. In addition, the advantages brought on by innovation often bypass small-scale farmers and processors, as they experience significant difficulties in accessing technologies and related training. What is more, local producers and processors are subjected to the pressure of buyers importing to the north, whereas new consumers such as China, Russia, Japan, and the Middle East are joining historical actors such as Europe and the USA. This group of retailers and importers has the power to determine price, quality, and delivery of the products to comply with their standards for food imports, thus limiting access to markets for smaller and less organized cashew producers. The emergence of new actors in the international markets, resulting in a higher competition among producers, has been leading to the liberalization of the cashew sector that has resulted in an increasing number of workers becoming "informal." This trend, apart from making quantification of laborers in the cashew industry difficult, has caused workers to be unprotected by labor legislation while receiving low wages and being subject to health-threatening working conditions. In this framework, women that make up the majority of the workforce in the cashew industry are more severely impacted than men, as they often experience inequalities due to gender issues.

Therefore, more research should be carried out to thoroughly understand the governance of cashew nut production chain, with the aim of identifying the linkages between its nodes and the distribution of gains along it. Such analysis should be conducted acknowledging the fact that given the nature of the cashew production system, local value chain analysis has to be combined with contextualized livelihood analysis.

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