Potato Research (2019) 62:281–304
https://doi.org/10.1007/s11540-019-9411-x

Not by Bread Alone: Estimating Potato Demand in India in 2030

Gregory J. Scott[1,2] · Athanasios Petsakos[3] · Victor Suarez[3]

Received: 5 January 2018 / Accepted: 15 January 2019 /
Published online: 21 February 2019

Abstract
While much of the literature on future food consumption in India in the decades ahead focuses on cereals, this paper presents estimates of potato demand to the year 2030 according to three different scenarios. Estimated increases in total food demand for potato range from 20 to 30 million metric tonnes and from 5.5 to 15 kg capita^{-1} year^{-1}, with modest, if any, increases in foreign trade. These estimates highlight the potato's growing importance in Indian diets as food consumption patterns continue to evolve while maintaining their traditional roots. They also call for a series of public and private initiatives to facilitate the realization of the potato's potential future contribution to food consumption and nutrition in India. These include renewed support for research and development as relates to improved technologies for the potato sector both on and off the farm. It also involves opportunities for industry to combine market-driven innovations to achieve commercial success with benefits for growers, consumers and the environment as well.

Keywords Climate change · Cold storage · Consumption · Diets · IMPACT · Industry · Markets · Policy · Processing · Technology · Trade

Introduction

Over the last half century, the world has witnessed some dramatic shifts in food consumption patterns (Kearney 2010). Diets have evolved, shifted and continue to change for a variety of reasons (Msangi and Rosegrant 2011). Rising incomes, increases in food production, demographic expansion accompanied by migration from

✉ Gregory J. Scott
gscott@pucp.pe

1 CENTRUM Católica Graduate Business School, Lima, Peru

2 Pontificia Universidad Católica de Perú, Lima, Peru

3 Social and Nutrition Sciences Division, International Potato Center, Lima, Peru

the countryside to urban areas, as well as new communication, transportation, food production and cooking technology, female participation in the workforce and a renewed focus on health and nutrition are but a few of the many factors driving these developments (Wilkinson and Rocha 2009; Kumar 2017).

Changes in food consumption patterns have perhaps been even more noteworthy in developing countries, particularly over the last 25 years and particularly in Asia (Timmer et al. 2010; Reardon et al. 2012; Scott and Suarez 2012a; Timmer 2014; Kumar and Joshi 2016a; Vengatesh et al. 2016). With accelerated economic growth, continued albeit declining population expansion and growing urbanization, shifts in eating habits have become more pronounced (Pingali 2006; Radhakrishna 2006; Scott and Suarez 2012b). With rising awareness of environmental degradation and the potential impact of the advent of climate change, concerns over the prospects for food consumption in Asian food systems have become that much more common (Timmer 2017).

In that context, efforts have focused on modelling future demand for those food crops that have long formed the basis of the global diet—cereals such as rice, wheat and maize—particularly in Asia (Alexandratos and Bruinsma 2012; FAO 2016; OECD/FAO 2016). However, the potential contribution of other food commodities also merits systematic analysis. This paper focuses on future scenarios for potato consumption and utilization in India to 2030.

Our interest is in India because with over 1.2 billion people, it will become the world's most populous country before 2030 (United Nations 2015; IndiaTimes 2017). Hence, future food consumption patterns in India merit particular attention at both the national and global level.

Our interest in potato in India reflects in part the remarkable rise in potato consumption over the last half century. Per capita consumption rose from a meagre 3.5 kg person^{-1} in 1962 to over 24 kg person^{-1} in 2013 (Fig. 1), with recent estimates of availability capita^{-1} at the state level well above (> 70 kg year^{-1} in West Bengal) and below (< 1 kg year^{-1} in Tamil Nadu) that national average (NCCD 2015).[1] Moreover, contrary to previously anticipated declines in consumption due to a rise in incomes (Walker et al. 1999), nearly half of that increase occurred since 2003 along with rising incomes (Trading Economics 2017; Rana and Anwer 2018). Factors driving these developments include the:

- desire by consumers to diversify their eating habits beyond simply greater consumption of cereals as their incomes continued to increase;
- neutral taste and gastronomic versatility of the tuber;
- potato's nutritional attributes as a source of vitamins and minerals, particularly when consumed with the skin intact (Woolfe 1987);
- strong vegetarian tradition in Indian diets; and, the
- relatively modest levels of per capita consumption of potato currently in relation to the levels prevailing in other developing countries in Asia (Scott and Suarez 2012a).

[1] Whereas per capita availability at the national level is a rough and ready approximation of per capita consumption, the figures for the state level mentioned here must be considered with greater caution because they are annualized totals based on monthly estimates to allow for comparison with national figures and due to the absence of statistics for trade between states within national borders.

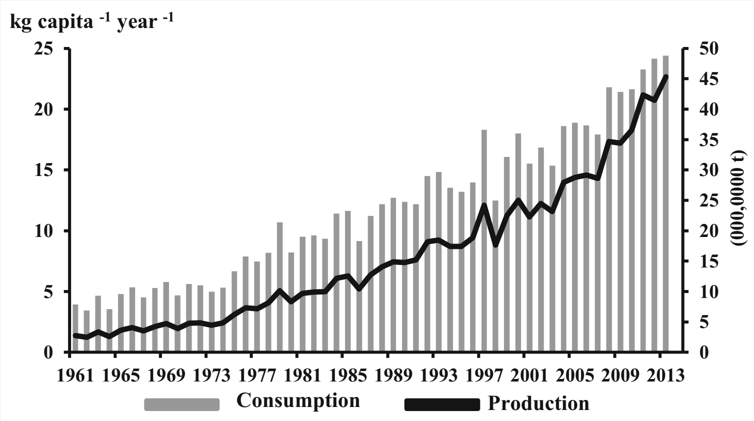

Fig. 1 Evolution of annual production and per capita consumption of potato in India, 1961–2013. Source: FAO (2017)

Partly in response to these emerging trends, potato consumption and utilization in the developing countries of Asia, including India, have been the focus of a small number of earlier studies (Anonymous 1995; CPRI 1997, 2011; Scott et al. 2000). However, the historical databases that many of these studies drew upon are now outdated with their time horizons already well in the past (2000) or within relatively close proximity (2020). In that regard, it is noteworthy that the most optimistic estimate of total demand for potato in India in 2020—43.3 million tonnes—had already been surpassed reaching over 50 million tonnes in 2011 (Scott et al. 2000, FAO 2017). Moreover, FAO's most recent published estimates of future demand for potato in developing countries in 2050 do not include country-specific figures for potato in India (Alexandratos and Bruinsma 2012). Furthermore, the small number of recent studies that have generated estimates of future scenarios for potato in India has been focused only on potato and only on yields (Jaggard et al. 2010; Kumar et al. 2011, 2015; Dua et al. 2015) or provided only limited information on the methodology utilized or assumptions employed to arrive at the array of estimates of consumption and utilization presented (CPRI 2011, 2015). Other studies of future food demand in India have focused largely on cereals, pulses and other commodities, but not potato (Kumar and Joshi 2016b).

In that context, this paper presents estimates of potato demand in India to the year 2030 according to high, moderate and low demand growth scenarios. In that regard, the following section presents the basic model utilized to generate the aforementioned estimates including the specification of the economic, demographic, climatic, technological, and policy-related parameters utilized in each of the scenarios. The paper then reviews the key results. This includes interpreting the growth rates in total food demand for potato, seed, and other uses that resulted in the absolute levels calculated for each of those variables in each of the scenarios and the corresponding estimates for per capita consumption and trade. The paper then addresses the implications of these estimates. These include policies to help facilitate their realization as well as specific measures to capitalize on the potential they represent in terms of improved marketing for growers and consumption and nutrition for consumers in India. It also reviews various opportunities for industry highlighting those with the greatest potential to combine commercial success with benefits for producers, consumers and the environment as well, before mentioning some topics for future research.

The IMPACT Model

Future scenarios for potato demand in India generated for this paper utilized the 2015 version of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (Rosegrant and the IMPACT Development Team 2012; Robinson et al. 2015). IMPACT is a multi-period, agricultural partial equilibrium economic model, linked with a set of crop, climate, and water models. The integrated foresight modelling framework built around IMPACT has been used extensively to examine various issues related to world agriculture, including commodity-specific supply and demand at various geographical scales over different time periods (e.g. Scott and Kleinwechter 2017) and also in analyses related to climate change impacts on agriculture and global food security (e.g. Nelson et al. 2010, 2018; Springmann et al. 2017).

This version of IMPACT includes 62 agricultural commodities and distinguishes 159 geopolitical regions. Total demand for a given commodity, potato in this case, is the sum of individual demand components, namely household food demand, feed demand and intermediate demand for other uses like seed or industrial use. For every year simulated by IMPACT, food demand QF for commodity i in country c is given by the following isoelastic function:

$$QF_{i,c} = FInt_{i,c} \times \Delta Pop \times (\Delta GDP)^{\varepsilon} \times \left(\Delta P_{i,c}\right)^{\delta} \times \prod_{j \neq i} \left(\Delta P_{j,c}\right)^{\delta} \quad (1)$$

where $FInt$ is the intercept (i.e. food demand at the initial year of the simulations, as reported in FAO (2017). The remaining components of the equation act as shifters from $FInt$:

- ΔPop is population growth;
- ΔGDP is the change in per capita income;
- ε is the income elasticity of demand for commodity i;
- ΔP is the price change of commodity i and any other competing commodity j;
- δ is the price elasticity of demand;
- $(\Delta P_{i,\ c})^{\delta}$ represents own-price response of demand and $\prod_{j \neq i} \left(\Delta P_{j,c}\right)^{\delta}$ represents cross-price responses of demand.

The specification for intermediate demand QI is similar to Eq. (1), and also depends on population, per capita GDP and price effects. By way of contrast, demand for feed QL of commodity i in country c is determined by feed prices and the total feed requirements of the livestock sector in country c. It is also given by an isoelastic function, specified as follows:

$$QL_{i,c} = \sum_{v} \left(SL_{v,c} \times Req_{i,v,c} \right) \prod_{K} \left(\Delta P_{K,c} \right)^{\xi} \tag{2}$$

where

- v denotes the livestock activities.
- SL is the production volume of livestock activity v.
- Req is the i feeding requirement for livestock activity v.
- K is the set of all commodities that can be used as feed, which includes i and competing commodities j.
- ξ is the price elasticity of demand for each feed commodity in K.

Although the 2015 version of IMPACT includes estimates of consumption, utilization, trade, prices, and agricultural production up to 2050, the current study emphasizes the presentation and interpretation of calculations of future demand scenarios with a time horizon of 2010 to 2030. In that regard, the end point represents a year far enough into the future to justify alternative estimates about an uncertain outcome. It thereby allows for the on-going effects of income changes, population growth and climate change to manifest themselves while capitalizing on the growing body of literature analysing historical trends for potato consumption and utilization in India over the last five decades from which previous estimates of future potato demand did not have the benefit. Furthermore, by focusing on 2030, the results of this study leave time for plans to be made and implemented in relation to projected scenarios as well as to provide a benchmark to build on in future modelling efforts focused on subsequent decades. While calculating estimates for 2010–2030, we do so acknowledging that these calculations are part of a long-term, continuous process and, in the case of climate change, before much greater changes in climate patterns are considered likely to occur (Kumar et al. 2015). We also consider that a much longer period for projections raises the prospect of more known and unknown uncertainties (Scrieciu et al. 2013), with the associated estimates becoming more problematic to incorporate into the modelling exercise thereby undermining the credibility of the results (Rosen and Guenther 2015).

Key Components and Scenario-Specific Parameters

In this paper, we define three scenarios for potato household food demand by adjusting the income elasticity of demand ε in Eq. (1) according to different future change pathways that draw on research performed under the auspices of the Intergovernmental Panel on Climate Change (IPCC). Specifically, the scenarios are based on combinations of Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs), both of which have been developed by the IPCC for the purpose of carrying out foresight analysis related to climate change, while also accounting for possible socio-economic changes like population and economic growth.

SSPs represent alternative trends in socio-economic and natural systems and incorporate different assumptions related to challenges for mitigation and adaptation to climate change. These assumptions are expressed in terms of different future growth rates in income, population, and urbanization for large world regions (O’Neil et al.

2014). On the other hand, RCPs represent different climate change pathways, incorporating assumptions about radiative forcing (i.e. the positive change in Earth's surface-troposphere energy budget that is responsible for climate change) from concentrations of greenhouse gases and other forcing agents (Van Vuuren et al. 2011). The radiative forcing assumptions posited by RCPs are translated into daily, or monthly, climate projections at various spatial resolutions with global climate models, most formally known as Earth System Models (ESMs).

Although this paper focuses on future food demand in India, the foresight analysis performed and the findings presented herein are part of a larger set of estimates that include food supply as well, under additional assumptions regarding agricultural technology and crop yields.[2] For the overall study, we combined three different SSPs with three different RCPs to link a set of socio-economic assumptions to a specific climate change pathways and associated assumptions regarding technological change in food production to those for food consumption and utilization. Following Petsakos et al. (2018) and Wiebe et al. (2015), the selected combinations were SSP1–RCP4.5, SSP2–RCP6.0, and SSP3–RCP8.5 (Table 1). The three SSPs correspond to pathways of high, medium and low mitigation and adaptation challenges respectively (O'Neil et al. 2014), while the number accompanying the RCPs expresses the corresponding maximum radiative forcing by 2100 (in watts m^{-2}), with higher numbers indicating a more severe climate change pathway.

More specifically, SSP1–RCP4.5 is the most optimistic of the three scenarios, positing high economic growth and low population growth rates (Table 2) combined with less demanding climatic conditions and more favourable assumptions regarding the evolution of technological change (Table 1). The income elasticity of demand for potato is also assumed to be highest among the three scenarios.[3] As such for this study, the SSP1–RCP4.5 combination represents the high demand growth scenario.

SPP2–RCP6.0 represents the moderate demand growth scenario. It assumes solid, albeit more moderate, demographic, and economic growth rates (Table 2) along with more challenging climatic conditions than SSP1–RCP4.5. Scenario SPP2–RCP6.0 is also linked to intermediate assumptions regarding the growth rate for technological change (Table 1).

The SSP3–RCP8.5 is the most pessimistic scenario with relatively high population growth rates, low economic growth, and more adverse climatic conditions (Tables 1 and 2). These assumptions, combined with a more conservative outlook for technological change and lower income elasticities of demand, constitute the low demand growth scenario.

The quantification of the different RCPs in each of the above scenarios in terms of daily climate projections included four ESMs integrated into IMPACT. These are the Model for Interdisciplinary Research on Climate (MIROC-ESM, Watanabe et al. 2011), ESM from the Pierre Simon Laplace Institute (IPSL-CM5A, Dufresne et al. 2013), the Geophysical Fluid Dynamic Laboratory ESM (GFDL-ESM2M,

[2] See Scott et al. (2019) for information about how specific technology assumptions are modelled for each scenario and lead to the food supply estimates that complement the food demand figures presented here.

[3] The final values of the potato income elasticities for the three scenarios, together with those for wheat and rice are illustrated in Appendix Table 11

Table 1 Specification of simulation scenarios according to different socio-economic, climate and technology assumptions

Climate scenarios	Socio-economic scenarios		
	High GDP growth, low population growth (SSP1)	Moderate GDP and population growth (SSP2)	Low GDP growth, high population growth (SSP3)
Low impacts (RCP4.5)	High demand—rapid growth technology scenario	–	–
Moderate impacts (RCP6.0)	–	Baseline demand and technology scenario	–
High impacts (RCP8.5)	–	–	Low demand and slow technology growth scenario

Source: IMPACT and calculations for this study

Dunne et al. 2012) and the Norwegian ESM (NorESM1-M, Bentsen et al. 2013). Each of these models incorporates different assumptions regarding the modelling of Earth's climate and therefore interprets a given RCP accordingly. The daily climate projections produced by the previous four ESMs were then used as data inputs for the crop growth model DSSAT (Decision Support System for Agrotechnology Transfer) (Jones et al. 2003), incorporated into the IMPACT modelling suite, in order to estimate the impact of climate on yields of potato and other crops, including rice and wheat.[4]

The SSP–RCP combinations selected for this study are consistent foresight scenarios for climate change research that assume similar mitigation costs (Van Vuuren et al. 2014). By also using an ensemble of ESMs to interpret each RCP, rather than a single model, the three scenarios, along with the additional supply and demand assumptions they incorporate, are able to capture a wide range of possible future changes in socio-economic and natural systems and can therefore provide a better description of India's food systems in the future.

All three scenarios assume the continuation of a set of benign policies toward the potato sector including:

- an absence of recurrent price controls or obligatory public procurement programmes (Rahman et al. 2019) for potato that might otherwise dampen producer/trader enthusiasm for greater production and marketing (Fuglie et al. 2000; Scott 2002; Reardon et al. 2012);
- support for the massive expansion in cold storage infrastructure to meet the capacity requirements associated with run-up in the volumes of harvested potatoes for sale as food or use as planting material (Dahiya and Sharma 1994; NCCD 2015; Anonymous 2017); and,
- investment in potato research and development to foster technological innovation in potato production and utilization (CPRI 2011, 2015).

[4] See Robinson et al. (2015) for more information about how DSSAT is linked with IMPACT.

Table 2 Gross domestic product (GDP) and population growth rates (% year^{-1}) in India under different scenarios

	Economic and demographic scenarios		
	SSP1	SSP2	SSP3
GDP/years			
2010–2014	6.39	6.55	6.68
2015–2019	6.79	6.80	6.84
2020–2024	6.84	6.17	5.51
2024–2029	6.66	5.36	4.21
Population/years			
2010–2014	1.17	1.33	1.45
2015–2019	0.96	1.20	1.42
2020–2024	0.78	1.04	1.33
2025–2029	0.61	0.90	1.24

Source: IMPACT (Robinson et al. 2015), where GDP and population growth rates are based on IIASA (2013)

Results

Moderate Demand Growth Scenario

According to the moderate demand growth scenario, total demand for potato in India will grow 3.11% year^{-1} on average during the period 2010–2030 (Table 3). While this annual average compound growth rate (ACR) may appear high, it actually represents a relatively conservative outlook for the future growth of potato demand. Actual total potato demand in India grew at nearly 7% year^{-1} during the decade 2001–2003 to 2011–2013 (Fig. 2). CPRI (2015) anticipates a much more ambitious ACR of 6% year^{-1} for potato demand up to 2050.

The moderate demand growth scenario consequently estimates that total potato demand in India will nearly double to reach 68.9 million tonnes by 2030 (Table 4). This increase reflects a combination of:

- India's massive population touching 1.5 billion in 2030 (IndiaTimes 2017);
- growing urbanization (Sankhe et al. 2010)—an estimated 40% of India's population or nearly 600 million people will be living in urban areas by 2030—and with that an increased demand for food away from home including restaurants as well as in the form of snacks and convenience foods (Pingali 2006; Scott and Suarez 2011; CPRI 2015);
- the relatively modest levels of per capita consumption of potato (22 kg year^{-1}) prevailing in the country at the outset of the 2010–2030 period (FAO 2017); and,
- the relatively strong income elasticity of demand for potato—in particular in relation to staple foods such as rice or wheat (Appendix Table 11).

The moderate demand growth scenario further estimates the ACR for food demand will average 2.84% year^{-1} and that of demand for "other uses" of potato to reach 3.81% year^{-1} (Table 3). The ACR for food demand includes both fresh and processed

Table 3 Average annual growth rates (% year^{-1}) for food, other uses, and total demand for potato in India 2010–2030, according to different scenarios

Climate model	Food			Other uses			Total demand		
	2030-1	2030-2	2030-3	2030-1	2030-2	2030-3	2030-1	2030-2	2030-3
A	3.34	2.79	2.32	3.92	3.76	3.44	3.50	3.07	2.64
B	3.31	2.74	2.21	3.87	3.71	3.33	3.46	3.02	2.53
C	3.40	2.90	2.41	3.98	3.88	3.54	3.56	3.18	2.73
D	3.46	2.91	2.49	4.04	3.89	3.63	3.62	3.18	2.81
E	3.38	2.84	2.36	3.95	3.81	3.48	3.54	3.11	2.68

Scenario: 1 = high demand growth, 2 = moderate demand growth, 3 = low demand growth; climate model: A = IPSL-CM5A-LR, B = MIROC-ESM, C = NORESM1-M, D = GFDL-ESM2M, E = four-model mean. Source: IMPACT model estimates generated for this study

potato products (e.g. potato crisps, flour) for direct human consumption. It constitutes the growth rate for over 70% of total demand when comparing absolute totals (Table 4) and reflects the potato's role in the average diet in India as most commonly that of a complementary vegetable with at least three noteworthy exceptions.

Firstly, at the peak of harvest in the major potato-producing states in the Indo-Gangetic plain, potatoes can become a seasonally more attractive food for all consumers. This is particularly true for the very poor and/or migrant labourers when as a flood of supplies appear, their meagre incomes preclude purchase of other food crops that are less readily available (Scott and Suarez 2011). Production figures in relation to cold storage capacity and utilization (see below) suggest that a disproportionate share—roughly 30%—of annual consumption takes place during and immediately after the

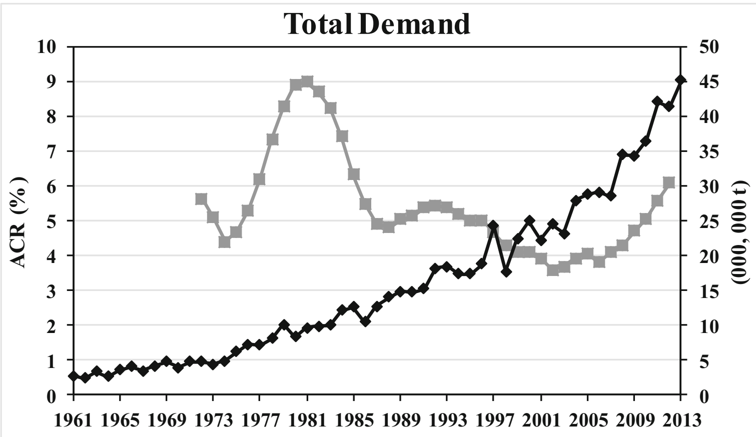

Fig. 2 Total demand for potato in India and ACRs for total demand in India, 1961–2013.[a] Source: FAO (2017) and calculations for this study. [a]Where each square represents the average compound growth rate (ACR) over a moving 10-year period with each of the points during each of the 10 years being a 3-year average, e.g. 1971–1973 vs 1961–1963, 1972–1974 vs 1962–1964 and where the growth rate is calculated using the following expression: Y = $b_0\, e^{b_1 t}$, i.e. $\ln(Y) = \ln(b_0) + b_1 t$; where Y = total demand; ln = natural log and ACR = (antilog $(b_1) - 1) \times 100$ and where each diamond represents total demand for potato (000,000 t) in India

Table 4 Total demand (000 t) for potato as food and for other uses in India in 2010 and estimates to 2030, according to different scenarios

Climate model	Food				Other uses				Total Demand			
	2010	2030-1	2030-2	2030-3	2010	2030-1	2030-2	2030-3	2010	2030-1	2030-2	2030-3
A	22,665	53,171	47,540	43,113	9529	21,348	20,691	19,378	36,185	74,519	68,231	62,491
B		52,766	47,064	42,218		21,172	20,468	18,944		73,938	67,531	61,163
C		53,827	48,589	43,954		21,631	21,184	19,787		75,458	69,773	63,741
D		54,468	48,658	44,658		21,910	21,217	20,130		76,379	69,875	64,788
E		53,558	47,963	43,486		21,515	20,890	19,560		75,074	68,852	63,046

Scenario: 1 = high demand growth, 2 = moderate demand growth, 3 = low demand growth; climate model: A = IPSL-CM5A-LR, B = MIROC-ESM, C = NORESM1-M, D = GFDL-ESM2M, E = four-model mean. Source: FAO (2017) for 2010 and IMPACT model estimates generated for this study

harvest months that vary by state but tend to be concentrated in February and March (NCCD 2015). In a similar vein, potato can also serve as a substitute for other foods, i.e. cereals during fasts for religious festivals.

Secondly, early potatoes in India—harvested in November and December in selected locations (e.g. the Punjab)—also receive premium prices for their superior taste and the social status their scarcity value conveys. These tubers are more like a high-priced, seasonal vegetable than a relatively cheap complementary or staple food. In parts of India, for example Meghalaya and West Bengal, the so-called native potatoes represent varieties introduced long ago and through negative selection produce small tubers that are associated with particular gastronomic or storage traits (CIP 2009). These tubers can also fetch a higher price for their culinary appeal and exotic commercial status.

Thirdly, French fries in large metropolitan areas such as Mumbai or New Delhi are a relatively expensive food item eaten by the more affluent, younger generation for their taste and convenience as well as their association with a certain Western life style. Such a consumption pattern for potato is commonly found in other large, cosmopolitan urban areas in other parts of developing Asia (Guenthner 2001, 2010; Watson 2006; Curtis et al. 2007; Scott and Suarez 2012b).

These estimates for future consumption are also grounded in the more general trends in eating habits in India previously enumerated and their relevance for potato in particular including the:

- strong vegetarian tradition in Indian diets (Reardon and Minten 2011);
- as of yet very minor (< 5%) percentage of potato consumption derived from processed food products, e.g. chips and French fries (CPRI 2015);
- rapid spread of fast foods elsewhere in developing Asia that has unrealized potential in India (Pingali 2006; Scott and Suarez 2012b); and,
- prospects for improvements in post-production value chain activities thereby making potato more competitive in terms of cost and quality control (Reardon et al. 2012).

The growth rate estimated for "other uses" as understood in this study is a composite figure covering, according to FAO, demand for (1) seed and (2) "waste", e.g. weight loss in cold storage or transit from farm to consumer and spoilage developing during packing and handling. No potatoes serve for animal feed in India as in other Asian countries (Scott and Suarez 2012a; FAO 2017) nor are there statistics indicating any processing of potatoes for industrial use. Given these considerations, the estimated growth rate for other uses according to the baseline scenario would appear to be particularly high for several reasons.

In India, the quantity in terms of weight of tuber seed or its equivalent used per hectare has declined over time as cut seed became a common practice and alternative types of planting material emerged, in particular mini-tubers (Scott and Suarez 2011; Fig. 3). Consequently, seed use as a share of total use declined from 17% in the early 1960s to 7% in 2011–2013 (Table 5).

The opposite has occurred with losses or waste. Their share of total demand rose from 17% in the early 1960s to some 24% in 2013 (Table 5) with both percentages having little, if any, empirical justification. The sharp rise in the absolute totals calculated as waste since 2007 (Fig. 4) seems particularly suspect. Earlier studies that attempted to quantify losses from waste tended to focus on storage with less attention

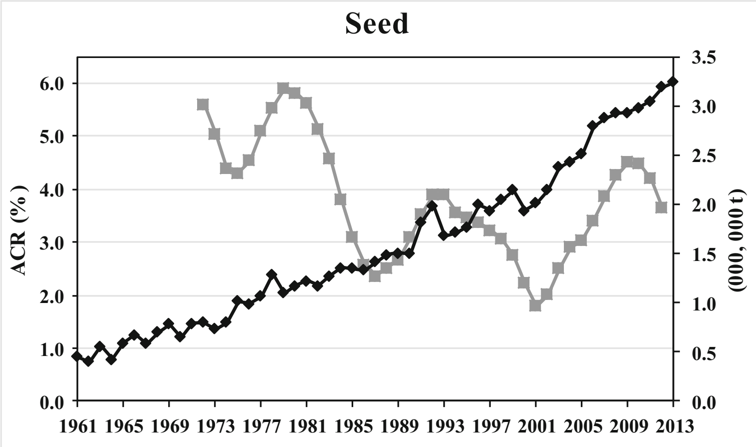

Fig. 3 Total seed use for potato in India and ACRs for total seed use in India, 1961–2013.[a] Source: FAO (2017) and calculations for this study. [a]Where each square represents the average compound growth rate (ACR) over a moving 10-year period with each of the points during each of the 10 years being a 3-year average, e.g. 1971–1973 vs 1961–1963, 1972–1974 vs 1962–1964 and where the growth rate is calculated using the following expression: Y = $b_0\ e^{b_1 t}$, i.e. ln(Y) = ln(b_0) + $b_1 t$; where Y = seed; ln = natural log and ACR = (antilog (b_1) − 1) × 100 and where each diamond represents total seed potato demand (000,000 t) in India

given to wholesaling activities forward through to final human consumption. They estimated that losses during cold storage—where most potatoes are kept after harvest—were 5% of the volumes stored (Fuglie et al. 2000). Moreover, recent field research on value chain transactions aside from storage involving potato growers, cold store operators, wholesalers, retailers and consumers found that losses were only 1% (Reardon et al. 2012). In addition, estimates of waste and losses of 24% of total available domestic supply are much higher than comparable percentages for other developing countries in Asia—estimates for China are 6% according to FAO data (Scott and Suarez 2012b). The weight of the evidence therefore suggests that the estimated magnitude of losses from other uses is exaggerated. Rather, it would appear that 10–15% or more of total demand currently assigned to the losses sub-category are and will continue to be devoted to direct human consumption instead.

Table 5 Food balance sheets for potato in India, 1961–2013

Uses	1961–1963 (000 t)	Percent	1978–1980 (000 t)	Percent	1995–1997 (000 t)	Percent	2011–2013 (000 t)	Percent
Food	1880	66	6160	70	14,784	74	29,605	69
Seed	469	17	1186	13	1902	9	3159	7
Processing	0	0	0	0	0	0	0	0
Others[a]	483	17	1507	17	3427	17	10,083	24
Total domestic available supply	2832	100	8854	100	20,114	100	42,847	100

Source: FAO (2017) and calculations for this study

[a] According to FAO (2017) "other uses" refers to "waste" and "other uses", although in previous years it referred only to waste (Anonymous 1995; Horton 1988)

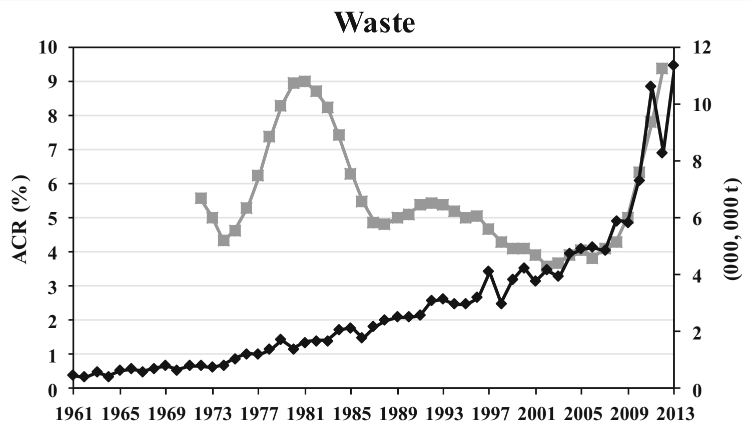

Fig. 4 Total losses for potato in India and ACRs for total losses in India, 1961–2013.[a] Source: FAO (2017) and calculations for this study. [a]Where each square represents the average compound growth rate (ACR) over a moving 10-year period with each of the points during each of the 10 years being a 3-year average, e.g. 1971–1973 vs 1961–1963, 1972–1974 vs 1962–1964 and where the growth rate is calculated using the following expression: Y = $b_0\, e^{b_1 t}$, i.e. $\ln(Y) = \ln(b_0) + b_1 t$; where Y = waste; ln = natural log and ACR = (antilog (b_1) − 1) × 100 and where each diamond represents total potato waste (000,000 t) in India

According to the moderate demand growth scenario, per capita potato consumption in India will reach 31.4 kg year^{-1} in 2030 (Table 6). While this represents a 50% increase in average per capita in-take during the two decades, recent estimates point to the potential for greater consumption. Examples include those locations where per capita availability remains relatively low even with sharp increases in output (e.g. 27.6 kg year^{-1} in Gujarat) or where improvements in transportation and the cold storage chain can facilitate consumption increases despite relatively low production levels (NCCD 2015). In broader terms, these estimates of an increase in per capita consumption represent simply the most recent manifestation of the growing importance of potato in the diet in India that emerged over the last half century (Table 7) due to a variety of factors (Scott and Suarez 2011). These include the:

Table 6 Annual average food demand (kg capita^{-1}) for potato, wheat and rice in India in 2010 and estimates to 2030, according to different scenarios

Climate model	Potato				Wheat				Rice			
	2010	2030-1	2030-2	2030-3	2010	2030-1	2030-2	2030-3	2010	2030-1	2030-2	2030-3
A		36.4	31.1	26.9		60.1	59.2	57.9		66.7	66.3	65.0
B	21.8	36.2	30.8	26.3	56.3	59.8	59.2	57.7	68.6	66.4	66.1	64.8
C		36.9	31.8	27.4		60.3	59.3	58.3		67.0	66.5	65.6
D		37.3	31.8	27.8		60.2	59.3	58.3		66.8	66.2	65.5
E		36.7	31.4	27.1		60.1	59.3	58.1		66.7	66.3	65.2

Scenario: 1 = high demand growth, 2 = moderate demand growth, 3 = low demand growth; climate model: A = IPSL-CM5A-LR, B = MIROC-ESM, C = NORESM1-M, D = GFDL-ESM2M, E = four-model mean. Source: FAO (2017) for 2010 and IMPACT model estimates generated for this study

- desire by consumers to diversify their eating habits beyond simply greater consumption of cereals as their incomes increase.
- neutral taste and gastronomic versatility of the tuber,
- tuber's nutritional attributes as a source of vitamins and minerals, particularly when consumed with the skins intact (Woolfe 1987),
- massive expansion of cold storage facilities to over 27 million tonnes that enables 70% of yearly consumption to take place after the annual harvest largely concentrated during February and March (Anonymous 2017), and,
- persistence of vegetarian diets among Indian households as a gastronomic tradition grounded in national culture (Reardon and Minten 2011).

In the moderate demand growth scenario, net trade is estimated to be a meagre 181,000 t—actually slightly less than observed potato exports in 2010 (FAO 2017)—but with considerable dispersion above and below the mean value (Table 8). As such, this estimate for net trade is in line with a half century of statistics showing that

Table 7 Annual average consumption of select food commodities in India, 1961–2013

	1961–1963	1971–1973	1981–1983	1991–1993	2001–2003	2011–2013
(kg capita^{-1} year^{-1})						
Bananas	4.1	4.5	4.9	7.8	10.2	17.8
Barley	4.7	3.6	2.2	1.4	1.0	0.9
Beans	3.0	2.9	3.6	3.4	2.9	3.2
Cassava	3.7	9.5	7.1	5.8	5.5	6.2
Fish, seafood	2.0	2.7	3.0	4.0	4.8	5.1
Fruits	25.6	25.1	25.4	30.0	35.6	53.3
Maize and products	8.0	7.9	7.8	6.1	6.2	6.4
Meat	3.7	3.6	3.9	4.2	4.1	4.0
Milk	37.1	34.2	43.0	53.1	62.1	84.7
Millet	15.3	14.4	12.7	9.5	9.0	8.2
Potatoes	4.0	5.4	9.5	13.8	15.9	23.9
Rice (Milled equivalent)	67.6	64.6	66.0	75.5	69.1	70.2
Sorghum and products	17.0	12.8	14.1	10.6	5.9	4.3
Vegetables	37.7	44.5	49.2	52.3	64.8	84.7
Wheat and products	28.5	41.1	47.1	59.5	60.9	58.8
(kcal capita^{-1} day^{-1})						
Total	2012	2007	2098	2300	2300	2450
Including % from						
Cereals	64.2	65.5	65.2	64.8	60.5	55.7
Rice (milled equivalent)	33.3	31.9	31.2	32.6	29.8	28.4
Wheat	12.1	17.5	19.2	22.1	22.6	20.5
Animal products	5.5	5.3	6.2	6.9	7.9	9.6
Potatoes	0.4	0.5	0.8	1.1	1.3	1.8

Source: FAO (2017) and calculations for this study for all years but one, exports remained less than 300,000 t year^{-1} even as production grew remarkably (Dahiya and Sharma 1994; FAO).

More fundamentally, these figures reflect a series of underlying factors discouraging exports of potatoes and potato products. These include (i) uncertainty about available supplies and export prices in relation to ever-growing domestic demand; (ii) limited infrastructure in the prevailing export cold chain to handle a bulky, semi-perishable commodity like fresh potato (NCCD 2015); and (iii) competition from established exporters in Europe or North America that ship to the same potential markets in the Gulf States and Southeast Asia (Scott and Suarez 2011). As a result, the moderate demand growth scenario suggests that in the continuous interplay of supply and demand, any movement toward a significant deviation from the estimated net trade figure would most likely be dampened by countervailing forces conducive to the domestic market, absorbing what otherwise might have been exported. In other words, “exports” would take place from those states in India with higher per capita availability to markets in those neighbouring states with lower per capita supply (NCCD 2015).

High Demand Growth Scenario

Based on a more rapid growth scenario, as represented by the SSP1–RCP4.5 combination and the related technology and demand assumptions, total demand for potato in India grows at a faster rate—3.54% year^{-1} versus 3.11% year^{-1}—than in the moderate demand growth scenario (Table 3). The associated absolute demand estimates include 9% higher total demand, 75 million tonnes, driven by a sharply higher ACR for food demand—3.38% year^{-1} versus 2.84% year^{-1}, resulting in a 17% higher per capita consumption of potato, 36.7 kg year^{-1} versus 31.4 kg year^{-1}, than that estimated in the moderate demand growth scenario (Tables 3, 4 and 6).

This set of demand estimates partly reflects greater optimism about the prospects for future consumption of processed potato products made possible by, among other things, greater female participation in the workforce and the associated demand for easier to prepare meals and snacks. It would also include more potato consumption in processed form away from home (e.g. schools, colleges) and eating out (restaurants, quick service establishments). As India becomes a more urban, less predominantly rural country in the years ahead (Sankhe et al. 2010), the high demand growth scenario envisions that such non-traditional eating habits may well spur added potato consumption more than

Table 8 Potato net trade (000 t) in India in 2010 and estimates to 2030

Climate model	2010	2030–1	2030–2	2030–3
A		1565	−5906	4240
B	191	2344	3856	−1792
C		336	1978	−1304
D		−6400	795	−4346
E		−1322	181	−2921

Scenario: 1 = high demand growth, 2 = moderate demand growth, 3 = low demand growth; climate model: A = IPSL-CM5A-LR, B = MIROC-ESM, C = NORESM1-M, D = GFDL-ESM2M, E = four-model mean. Source: FAO (2017) for 2010 and IMPACT model estimates generated for this study

in the case of the moderate demand growth scenario. In effect, it anticipates that faster economic growth (Tables 1 and 2) will facilitate a stronger preference for greater convenience associated with newly emerging eating habits and continued diversification of diets away from the cereals (Table 7).

As a response to the more rapid growth in population and economic output, the high demand growth scenario envisions an increase in imports—1.3 million tonnes (Table 8), or < 2% of total demand, to meet domestic potato utilization requirements. However, as the quantity of imports is a relatively meagre percentage of domestic demand, it may ultimately be covered by squeezing more tubers for direct human consumption out of the commodity value chain for potato. In effect, as higher prices resulting from stronger demand will contribute to such things as reducing waste from what appears to be an unrealistic absolute total (Table 4) for the reasons previously mentioned, the overall impact may well leave little need for imports.

Low Demand Growth Scenario

The low demand growth scenario is based on a more pessimistic set of assumptions regarding economic and population growth (Table 2), compounded by more adverse changes in climatic conditions, expressed by the SSP3–RCP8.5 combination (Table 1). It also posits slower technology growth and lower income elasticities of demand for potato (Appendix Table 11).

Slower economic growth helps cut the ACR for food demand for potato to 2.36% year^{-1} versus 2.84% year^{-1} in the moderate demand growth scenario (Table 3). The lower ACR results in lower per capita consumption of potato—27.1 kg year^{-1} versus 31.4 kg year^{-1} in the moderate demand growth scenario—as consumers cut back their in-take of starchy staples such as rice and wheat by a lesser amount (Table 6).

Total demand for potato consequently reaches an estimated 63 million tonnes or some 5.8 million tonnes (8%) less than the 68.85 million tonnes estimated according to the moderate demand growth scenario (Table 4). The net effect is a rise in imports estimated to reach 2.9 million tonnes by 2030 (Table 8), or 5% of total potato demand, as more challenging environmental conditions dampen further increases in potato production and productivity (Table 9).

Discussion

Under all three scenarios, India will see a 20–30 million tonnes increase in potato demand by 2030 enabling noteworthy increases in per capita potato consumption. Given that situation, among the foremost opportunities for private investment are those related to the cold storage industry. Some 60–70% of the potatoes produced in India are utilized after the harvest has taken place (Reardon et al. 2012). Cold storage is the principal modality for keeping the tubers.

These demand estimates indicate the need for 16 to 24 million tonnes more of cold storage capacity—beyond an estimated 27 million tonnes already available as of 2017 (Table 10). They also point to the need for upgrades or replacement of ageing current capacity as part of a major effort to improve energy efficiency in such units and the quality of the tubers subsequently made available for human consumption or use as planting material (NCCD 2015). A related opportunity concerns new technology for

Table 9 Area, yield and production of potato in India in 2010 and estimates to 2030, according to different scenarios

Climate Model	Area (000 ha)				Yield (t ha^{-1})				Production (000 t)			
	2010	2030-1	2030-2	2030-3	2010	2030-1	2030-2	2030-3	2010	2030-1	2030-2	2030-3
A		2724	2561	2543		26.8	24.3	22.9		72,954	62,325	58,250
B	1835	2773	2692	2600	19.9	27.5	26.5	22.8	36,185	76,282	71,388	59,370
C		2739	2640	2562		27.7	27.2	24.4		75,794	71,751	62,437
D		2638	2636	2512		26.5	26.8	24.1		69,978	70,671	60,443
E		2719	2632	2554		27.1	26.2	23.5		73,752	69,033	60,125

Scenario: 1 = high demand growth, 2 = moderate demand growth, 3 = low demand growth; climate model: A = IPSL-CM5A-LR, B = MIROC-ESM, C = NORESM1-M, D = GFDL-ESM2M, E = four-model mean. Source: Scott et al. (2019)

energy saving, if not energy substituting (e.g. solar) in the years ahead to reduce dependence on the country's chronically deficient energy grid and the tendency for power cuts to undermine more effective cold storage management. Various recent commentators have noted the considerable unrealized potential for renewable energy in India (OECD 2017) and the potential for supply chain improvements in response to carbon emissions in India and elsewhere in the decades ahead (Carbon Trust-BSR 2017). The massive and expanding cold storage sector would appear then to be a prime candidate for the combination of policies governing trade and investment necessary to facilitate innovation in the form of renewable energy in this instance.

A related opportunity concerns the geographic distribution of cold storage capacity and its use. In the age of the Internet and with the growing use of mobile phones by potato farmers in India (Reardon et al. 2012), taking full advantage of India's noteworthy software capabilities might result in innovative public–private commercial partnerships. Specifically, more might be done to generate continuous quantitative estimates of the relationship between available cold storage capacity and use in relation to annual potato production in the high potato production states (and districts) of India: Uttar Pradesh, West Bengal, Bihar and Gujarat (Rana and Anwer 2018). Such data could facilitate more informed planning of private investments for the much needed future expansion of cold storage capacity rather than the apparent prevailing oversupply in some locations (underutilized existing capacity) (Reardon et al. 2012) and an undersupply in others (with the run up in production in certain states) (Table 10). Such a scenario seems particularly true given that government operating licences traditionally are required to open such facilities as well as facilitate the purchase and importing of the necessary equipment to make them operational (Dahiya and Sharma 1994; Fuglie et al. 2000; Scott and Suarez 2011; NCCD 2015; Anonymous 2017). It might also catalyse producers and traders to make more effective use of the cold storage capacity in the future.

Related opportunities linked to increased potato consumption involve further development of potato processing and processed potato products (Pandey et al. 2006; Pandey et al. 2009) as well as emerging niche markets for different types (e.g. organic) of fresh tubers. The latter would include improvements in packaging of fresh potatoes such as in

Table 10 Production, storage available and capacity (%) for storing potatoes during 1979–1980, 1989–1990, 2009 and 2016 for selected states

State	1979–1980 Production (000,000 t)	Cold storage[a] (000,000 t)	Capacity/production (%)	1989–1990 Production (000,000 t)	Cold storage[a] (000,000 t)	Capacity/production (%)
Uttar Pradesh	3.16	1.08	34.1	6.22	2.72	43.7
West Bengal	1.99	0.74	37.2	4.53	1.70	37.7
Bihar	1.03	0.32	30.9	1.46	0.68	25.2
Punjab	0.68	0.34	50.2	0.36	0.39	108
Gujarat	0.26	–	–	0.33	–	–
India	8.30[b]	3.01[b]	36.2[b]	14.7[b]	6.11[b]	41.4[b]

State	2009 Production (000,000 t)	Cold storage[c] (000,000 t)	Capacity/production (%)	2016 Production (000,000 t)	Cold storage[c] (000,000 t)	Capacity/production (%)
Uttar Pradesh	10.8	8.10	74.9	14.9	11.18	75.2
West Bengal	9.9	4.55	45.9	12.0	4.75	39.5
Bihar	5.03	0.92	18.2	6.34	1.13	17.9
Punjab	2.00	1.08	53.8	2.26	1.72	76.1
Gujarat	1.45	1.01	70.0	2.96	2.05	69.4
India	34.4[b]	19.56[b]	56.8[b]	48.0[b]	27.2[b]	56.8[b]

Source: Dahiya and Sharma (1994) for 1979–80, 1989–90; Directorate of Marketing and Inspection for 2009 (see http://pib.nic.in/newsite/mbErel.aspx?relid=168990); Anonymous (2017) for 2016

[a] Assumes 90% of the cold storage capacity is taken to be available for storing potatoes

[b] Totals may not sum as national figures include those for other states not listed above

[c] Assumes 80% of the cold storage capacity is taken to be available for storing potatoes

pre-weighed, sorted 5–10 kg packets, grading and sales by variety and/or geographic origin as has emerged in other developing countries (Devaux et al. 2016). As urbanization accelerates in the coming decade, this may well offer opportunities for supermarkets and other actors in food retailing in India (Reardon and Minten 2011; Sharma and Bhardwaj 2015) to capitalize on opportunities related to increased consumption of potatoes all the way from improving farm-to-market linkages to fresh product promotion and carry out meals that include the tuber in different prepared forms, as has proven highly successful in other developing countries (Lau 2008; Devaux et al. 2016). A related issue involves nutritious ways to prepare potatoes (e.g. baked rather than simply fried or boiled), a topic of growing interest as consumers in both industrialized and developing countries focus more on eating habits as a way of improving their health and that of their children (Priestly 2006; AAFC 2007) and overcoming some of the misconceptions often associated with potato consumption in developing countries (Woolfe 1987; Scott 2011).

As regards potato processing, it should be noted that although future population growth will mean increased urbanization, by 2030, roughly one billion people in India will still be living in the countryside. Under such circumstances, opportunities for building on prior research on village-level processing into such products as solar dried chips or rustic flour (Nave and Scott 1992; Scott et al. 1993) would appear likely to receive renewed interest. In that context, further applied innovation capitalizing on local capabilities with small-scale machinery (Tewari 2017) and the access to advances available through the Internet might well enable such processing activity to expand. For that to happen, however, will require overcoming the previously documented challenges associated with the economic, as opposed to technical feasibility of such processing operations, issues related to the minimum scale to achieve financial sustainability and the quality control and hygiene standards for such products produced for direct human consumption under rustic conditions (Scott and Suarez 2011).

In a similar spirit, any discussion about processed potato products in India that touches on the potential for starch (Rana 2011) would do well to recall the major restructuring of the potato starch industry that took place in Europe with the expansion of the European Union. Less efficient producers in places like Poland were driven out of the market by very large-scale, specialized processors in Western Europe (Haase and Haverkort 2006). The outcome left idle considerable excess capacity posed to re-start operations should prices for potato starch rebound in the future.

Lastly, every effort should be made to continue the habit of eating potatoes with their skins intact so as to optimize the nutritional benefits and avoid the potential adverse impact from overeating unhealthy foods (Jacobs and Richtel 2016; Anand 2017). The potential for adopting, then introducing currently available improved varieties with specific nutritional traits, such as high vitamin A and E contents, also merits particular attention (Chitchumroonchokchai et al. 2017) as do efforts to encourage greater consumption of fresh potato so as to optimize the in-take of the tuber's nutritional attributes (Woolfe 1987).

Conclusion

While much of the literature on future food consumption in India in the decades ahead focuses on cereals, this paper presents estimates for potato demand to the year 2030 according to three different scenarios. All three scenarios envision a substantial increase in consumption in both absolute and per capita terms with very modest, if any, increases in foreign trade. These results highlight the potato's growing importance in Indian diets as the king of all vegetables, as food consumption patterns continue to evolve while maintaining their traditional roots.

The implications of these estimates suggest a series of opportunities made more attractive due to increased demand for potato in India in the years ahead. These include initiatives based on the most likely increase in demand for expansion and improvements in cold storage hardware and software. They also point to growing consumption of processed potato products both in rural as well urban areas, the emergence of different niche markets for fresh potatoes intended to cater to particular tastes and preferences and the potential to make more effective use of the potato's nutritional attributes to target dietary deficiencies identified by previous research.

Topics for future research that merit the highest priority would include a better understanding of trade patterns in the domestic market. There is a great deal of good quality information about potato production in India but very little, if any, statistics on internal trade flows across states for potato marketing. Simple monitoring of cold storage capacity and utilization at the district level—akin to the district-wise estimates of production, area and yields—albeit on a more continuous as opposed to once-a-year basis would be a first step in that direction. A related topic would be research to foster an energy innovation breakthrough in cold storage industry. Breeding and varietal trials that not only incorporated post-harvest traits like retention of vitamin and mineral content in storage as well as the diffusion of those planting materials with good agronomic traits but also enhanced quantities of vitamins A and E would be highly desirable for their impact potential. Finally, further advances as regards estimates of future demand for potato in India would be a given as this study is but one point-in-time contribution toward that overall effort.

Acknowledgements This study was undertaken as part of the Global Futures and Strategic Foresight project (GFSF) of the CGIAR Research Program on Policies, Institutions, and Markets (PIM).

Funding information Funding support was provided by the CGIAR Research Program on Policies, Institutions and Markets (PIM). The opinions expressed here belong to the authors and do not necessarily reflect those of PIM or the CGIAR.

Appendix

Table 11 Income elasticities of demand used for this study

Year	Potato			Wheat	Rice
	SSP1–RCP4.5	SSP2–RCP6.0	SSP3–RCP8.5		
2010	0.6765	0.6150	0.5531	0.0808	0.0093
2011	0.6688	0.6080	0.5471	0.0812	0.0073
2012	0.6611	0.6010	0.5411	0.0816	0.0057
2013	0.6545	0.5950	0.5351	0.0820	0.0044
2014	0.6468	0.5880	0.5291	0.0824	0.0034
2015	0.6391	0.5810	0.5231	0.0828	0.0027
2016	0.6325	0.5750	0.5171	0.0833	0.0021
2017	0.6248	0.5680	0.5111	0.0837	0.0016
2018	0.6171	0.5610	0.5051	0.0841	0.0013
2019	0.6105	0.5550	0.4991	0.0845	0.0010
2020	0.6028	0.5480	0.4931	0.0849	0.0008
2021	0.5951	0.5410	0.4871	0.0853	0.0006
2022	0.5885	0.5350	0.4811	0.0858	0.0005
2023	0.5808	0.5280	0.4751	0.0862	0.0004
2024	0.5731	0.5210	0.4691	0.0866	0.0003
2025	0.5665	0.5150	0.4631	0.0871	0.0002
2026	0.5588	0.5080	0.4571	0.0875	0.0002
2027	0.5511	0.5010	0.4511	0.0879	0.0001
2028	0.5445	0.4950	0.4451	0.0884	0.0001
2029	0.5368	0.4880	0.4391	0.0888	0.0001
2030	0.5291	0.4810	0.4331	0.0892	0.0001

Source: IMPACT model estimates for this study

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

Agriculture & Agri-Food Canada (AAFC) (2007) Canadian potato situation and trends 2006–07. Agriculture & Agri-Food Canada, Ottawa

Alexandratos N, Bruinsma J (2012) World agriculture: towards 2030/2050. The 2012 revision. ESA Working Paper No 12,03. Agricultural Development Economics Division. Food and Agriculture Organization of the United Nations (FAO), Rome

Anand G (2017) One man's stand against junk food as diabetes spreads across India. New York Times Available at: https://www.nytimes.com/2017/12/26/health/india-diabetes-junk-food.html

Anonymous (1995) Potatoes in the 1990s: situation and prospects of the world potato economy. Food and Agriculture Organization of the United Nations (FAO) in collaboration with the International Potato Center (CIP), Rome

Anonymous (2017) Agricultural statistics at a glance 2016. Directorate of Economics and Statistics, Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Delhi

Bentsen M, Bethke I, Debernard JB, Iversen T, Kirkevåg A, Seland Ø, Drange H, Roelandt C, Seierstad IA, Hoose C, Kristjánsson JE (2013) The Norwegian Earth System Model, NorESM1-M—part 1: description and basic evaluation of the physical climate. Geosci Model Dev 6:687–720

Carbon Trust-BSR (2017) The CDP supply chain report 2016–2017. The Carbon Trust, London

Chitchumroonchokchai C, Diretto G, Parisi B, Giuliano G, Failla ML (2017) Potential of golden potatoes to improve vitamin A and vitamin E status in developing countries. PLoS One 12(11):e0187102

CIP (International Potato Center) (2009) World potato atlas: India. International Potato Center (CIP), Lima Available at: https://research.cip.cgiar.org/confluence/display/wpa/India

CPRI (Central Potato Research Institute) (1997) Vision—2020. CPRI, Shimla

CPRI (Central Potato Research Institute) (2011) Vision—2030. CPRI, Shimla

CPRI (Central Potato Research Institute) (2015) Vision—2050. CPRI, Shimla

Curtis K, McCluskey J, Wall T (2007) Consumer preferences and western style convenience foods. China Econ Rev 18:1–14

Dahiya PS, Sharma HC (1994) Potato marketing in India: status, issues and outlook. Social Science Department Working Paper No.1994–2. International Potato Center (CIP), Lima

Devaux A, Velasco C, Thiele G, López G, Bernet T, Reinoso I, Ordinola M (2016) Collective action for market-chain innovation in the Andes. In: Devaux A, Torero M, Donavan J, Horton D (eds) Innovation for inclusive value chain development: successes and challenges. International Food Policy Research Institute (IFPRI), Washington DC

Dua VK, Singh BP, Kumar S, Lal SS (2015) Impact of climate change on potato productivity in Uttar Pradesh and adaption strategies. Potato J 42(2):95–110

Dufresne JL, Foujols MA, Denvil S, Caubel A, Marti O, Aumont O, Balkanski Y, Bekki S, Bellenger H, Benshila R, Bony S, Bopp L, Braconnot P, Brockmann P, Cadule P, Cheruy F, Codron F, Cozic A, Cugnet D, De Noblet D, Duvel JP, Ethe C, Fairhead L, Fichefet T, Flavoni S, Friedlingstein P, Grandpeix JY, Guez L, Guilyardi E, Hauglustaine D, Hourdin F, Idelkadi A, Ghattas J, Joussaume S, Kageyama M, Krinner G, Labetoulle S, Lahellec A, Lefebvre MP, Lefevre F, Levy C, Li ZX, Lloyd J, Lott F, Madec G, Mancip M, Marchand M, Masson S, Meurdesoif Y, Mignot J, Musat I, Parouty S, Polcher J, Rio C, Schulz M, Swingedouw D, Szopa S, Talandier C, Terray P, Viovy N, Vuichard N (2013) Climate change projections using the IPSL-CM5 Earth System Model: from CMIP3 to CMIP5. Clim Dynam 40(9):2123–2165

Dunne JP, John JG, Adcroft AJ, Griffies SM, Hallberg RW, Shevliakova E, Stouffer RJ, Cooke W, Dunne KA, Harrison MJ, Krasting JP, Malyshev SL, PCD M, Phillipps PJ, Sentman LT, Samuels BL, Spelman MJ, Winton M, Wittenberg AT, Zadeh N (2012) GFDL's ESM2 Global Coupled Climate–Carbon Earth System Models. Part I: physical formulation and baseline simulation characteristics. J Climate 25(19): 6646–6665

FAO (Food and Agricultural Organization of the United Nations) (2016) The state of food and agriculture 2016. Climate change, agriculture and food security. FAO, Rome

FAO (Food and Agricultural Organization of the United Nations) (2017) FAOSTAT Food Balance Sheet and production statistics. FAO, Rome. Available at http://www.fao.org/faostat/en/#data/CC and http://www.fao.org/faostat/en/#data/QC. Accessed March 2017
Fuglie KO, Khatana VS, Ilangantileke S, Scott G, Singh J, Sumar D (2000) Economics of potato storage in Northern India. Quarterly J Int Agric 39(2):131–148
Guenthner J (2001) The international potato industry. Woodhead Publishing Limited, Cambridge
Guenthner J (2010) Past, present and future world potato markets: an overview. Potato J 37(1–2):1–8
Haase N, Haverkort A (eds) (2006) Potato developments in a changing Europe. Wageningen Academic Publishers, Wageningen
Horton D (1988) Underground crops: Long-term trends in production of roots and tubers. Winrock International, Morrilton
IIASA (International Institute for Applied Systems Analysis) (2013) SSP Database. Available at https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about. Accessed 2014
IndiaTimes (2017) UN projects India to become the world's most populated country by 2024. IndiaTimes. Available at: https://www.indiatimes.com/news/india/un-projects-india-to-become-world-s-most-populated-country-by-2024-324350.html
Jacobs A, Richtel M (2016) How big business got Brazil hooked on junk food. New York Times. Available at: https://www.nytimes.com/interactive/2017/09/16/health/brazil-obesity-nestle.html?_r=0
Jaggard K, Qi A, Ober ES (2010) Possible changes to arable crop yields by 2050. Phil Trans R Soc B 365: 2835–2851
Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Wilkens PW, Singh U, Gijsman AJ, Ritchie JT (2003) The DSSAT cropping system model. Eur J Agron 18(3):235–265
Kearney J (2010) Food consumption trends and drivers. Phil Trans R Soc B 365:2793–2807
Kumar P (2017) Food and nutrition security in India: the way forward. Agric Econ Res Rev 30(1):1–21
Kumar P, Joshi PK (2016a) Food consumption patterns and nutritional security among rural households: impact of cross-cutting rural employment policies. In: Brouwer F, Joshi PK (eds) International trade and food security: the future of Indian agriculture. Commonwealth Agricultural Bureau International (CABI), Wallingford, pp 19–28
Kumar P, Joshi PK (2016b) Food supply and demand projections to 2030: India. In: Brouwer F, Joshi PK (eds) International trade and food security: the future of Indian agriculture. Commonwealth Agricultural Bureau International (CABI), Wallingford, pp 29–63
Kumar SN, Aggarwal PK, Rani S, Jain S, Saxena R, Chauhan N (2011) Impact of climate change on Western Ghats, coastal and northeastern regions of India. Curr Sci 101:332–341
Kumar SN, Govindakrishnan PM, Swarooparani PM, Nitin C, Surabhi J, Aggarwal PK (2015) Assessment of impact of climate change on potato and potential adaptation gains in the Indo-Gangetic Plains of India. Int J of Plant Prod 9(1):1151–1169
Lau M (2008) Papa pre-frita congeladas, lavadas, seleccionadas y empacadas: La experiencia de autoservicios WONG. PowerPoint presentation at the First National Potato Congress. Huancayo. Available at www.minag.gob.pe, scrolling to "Especiales", category "Congreso de la Papa" and from there to numbers 1–4
Msangi S, Rosegrant M (2011) Feeding the future's changing diets. Implications for agricultural markets, nutrition, and policy. 2020 Conference paper 3. International Food Policy Research Institute (IFPRI), Washington, DC
Nave R, Scott G (1992) Village-level potato processing in developing countries: a case study of the SOTEC Project in India. In: Scott G, Wiersema S, Ferguson PI (eds) Product development for root and tuber crops Vol. I-Asia (Proceedings of the international workshop, Baybay, Philippines, 22 April-1 May 1991). VISCA(Visayas State Agricultural College), International Potato Center (CIP), Lima, pp 331–353
NCCD (2015) All India cold-chain infrastructure capacity (assessment of status & gap). NCCD, Delhi
Nelson GC, Rosegrant MW, Palazzo A, Gray I, Ingersoll C, Robertson R, Tokgoz S, Zhu T, Sulser TB, Ringler C, Msangi S, You L (2010) Food security, farming, and climate change to 2050. International Food Policy Research Institute (IFPRI), Washington DC
Nelson G, Bogard J, Lividini K, Arsenault J, Riley M, Sulser TB, Wiebe KD, Rosegrant MW (2018) Income growth and climate change effects on global nutrition security to mid-century. Nat Sustain 1(12):773–781
O'Neil BC, Kriegler K, Riahi K, Ebi KL, Hallegatte S, Carter TR, Mathur R, Van Vuuren DP (2014) A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Clim Chng 122(3):387–400
OECD (Organization for Economic Cooperation and Development) (2017) Developing renewable energy in emerging Asia. In: Economic outlook for Southeast Asia, China and India 2017. OECD, Paris, pp 139–163

OECD (Organization for Economic Cooperation and Development)/FAO (Food and Agricultural Organization of the United Nations) (2016) OECD-FAO Agricultural outlook 2016–2025. OECD, Paris
Pandey SK, Sarkar D, Singh SV (2006) Potato processing in India: today and tomorrow. Potato J 33(1–2):11–19
Pandey SK, Marwaha RS, Kumar D, Singh SV (2009) Indian potato processing story: industrial limitations, challenges ahead and vision for the future. Potato J 36(1–2):1–13
Petsakos A, Hareau G, Kleinwechter U, Wiebe K, Sulser TB (2018) Comparing modeling approaches for assessing priorities in international agricultural research. Res Eval 27(2):145–156
Pingali P (2006) Westernization of Asian diets and the transformation of food systems: Implications for research and policy. Food Policy 32:281–229
Priestly H (2006) How to think like consumers and win. In: Haase N, Haverkort A (eds) Potato developments in a changing Europe. Wageningen Academic Publishers, Wageningen, pp 189–198
Radhakrishna R (2006) Food consumption and nutritional status in India: emerging trends and perspectives. WP 2006–008. Indira Ghandi Institute of Development Research, Mumbai
Rahman A, Pingali P, Mittra B (2019) Food security and nutrition in rural India: understanding state level heterogeneity. World Food Policy 4(2)/5(1) forthcoming
Rana RK (2011) The Indian potato processing industry. Global comparisons and business prospects. Outlook Agr 40(3):237–243
Rana RK, Anwer MD (2018) Potato production scenario and analysis of its total factor productivity in India. Indian J of Agric Sci 88(9):1354–1361
Reardon T, Minten B (2011) Surprised by supermarkets: diffusion of modern food retail in India. J Agribus Dev Econ 1(2):134–161
Reardon T, Chen K, Minten B, Adriano L (2012) The quiet revolution in staple food value chains: enter the dragon, the elephant, and the tiger. Asian Development Bank and International Food Policy Research Institute (IFPRI), Manila
Robinson S, Mason-D'Croz D, Islam S, Sulser TB, Robertson R, Zhu T, Gueneau A, Pitois G, Rosegrant M (2015) The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). Model description for version 3, discussion paper 01483. International Food Policy Research Institute (IFPRI), Washington, DC
Rosegrant MW, Development Team IMPACT (2012) International Model for Policy Analysis of agricultural Commodities and Trade (IMPACT): model description. International Food Policy Research Institute (IFPRI), Washington DC
Rosen R, Guenther E (2015) The economics of mitigating climate change: what can we know? Tech Forecasting Soc Chng 91:93–106
Sankhe S, Vittal I, Dobbs R, Mohan A, Gulati A, Ablett J, Gupta S, Kim A, Paul S, Sanhvi A, Sethy G (2010) India's urban awakening: building inclusive cities, sustaining economic growth. McKinsey Global Institute. McKinsey and Company, Mumbai
Scott G (2002) Maps, models, and muddles: world trends and patterns in potato revisited. Potato Res 45:45–77
Scott G (2011) Tendencias cruzadas: el consumo y utilización de la papa en América Latina entre 1961 y 2007 y sus implicancias para la industria. Rev Latam Papa 16:1–38
Scott G, Kleinwechter U (2017) Future scenarios for potato demand, supply and trade in South America to 2030. Potato Res 60(1):23–45
Scott G, Suarez V (2011) Growth rates for potato in India 1961–2009 and their implications for industry. Potato J 38(2):100–112
Scott G, Suarez V (2012a) The rise of Asia as the centre of global potato production and some implications for industry. Potato J 39(1):1–22
Scott G, Suarez V (2012b) From Mao to McDonald's: emerging markets for potatoes and potato products in China 1961–2007. Am J Potato Res 89(3):216–231
Scott G, Wong D, Alvarez M (1993) Improving village-level processing in developing countries: the case of potatoes. Ecology of Food and Nutrition 30:145–163
Scott G, Rosegrant M, Ringler C (2000) Global projections for root and tuber crops to the year 2020. Food Policy 25(5):561–597
Scott G, Petsakos A, Juarez H (2019) Climate change, food security, and future scenarios for potato production in India to 2030. Food Sec, forthcoming https://doi.org/10.1007/s12571-019-00889-z
Scrieciu S, Rezai A, Mechler R (2013) On the economic foundations of green growth discourses: the case of climate change mitigation and macroeconomic dynamics in economic modelling. Wiley Interdisciplinary Review: Energy & Envir 2(3):251–268
Sharma A, Bhardwaj P (2015) Hypermarkets: growth and challenges perspective in. India Asian Pacific J of Marketing and Mgt Rev 4(7):18–26

Springmann M, Mason-D'Croz D, Robinson S, Wiebe K, Godfray CJ, Rayner M, Scarborough P (2017) Mitigation potential and global health impacts from emissions pricing of food commodities. Nat Clim Chang 7:69–74

Tewari VK (2017) Agricultural mechanisation in the state of West Bengal, India. In: Sattar MA, Biggs ST, Justice SE (eds) Rural mechanisation. A driver in agricultural change and rural development. Institute for Inclusive Finance and Development (InM), Dhaka, pp 191–202

Timmer CP (2014) The dynamics of agricultural development and food security in Southeast Asia: historical continuity and rapid change. In: Coxhead I (ed) Handbook of Southeast Asian Economics. Routledge, New York, pp 89–113

Timmer CP (2017) Food security, structural transformation, markets and government policy. Asia Pac Policy Stud 4(1):4–19

Timmer CP, Block S, Dawe D (2010) Long-run dynamics of rice consumption, 1960–2050. In: Pandey S, Byerlee D, Dawe D, Doberman A, Mohanty S, Rozelle S, Hardy B (eds) Rice in the global economy. Strategic research and policy issues for food security. International Rice Research Institute (IRRI), Manila, pp 139–174

Trading Economics (2017) India GDP per capita PPP, 1990–2017. Available at: https://tradingeconomics.com/india/gdp-per-capita-ppp

United Nations (2015) World population prospects. The 2015 revision. United Nations, New York

Van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard A, Hurtt GC, Kram T, Krey V, Lamarque J-F, Masui T, Meinshausen M, Nakicenovic N, Smith SJ, Rose SK (2011) The representative concentration pathways: an overview. Clim Chang 109(1):5–31

Van Vuuren DP, Kriegler E, O'Neill BC, Ebi KL, Riahi K, Carter TR, Edmonds J, Hallegatte S, Kram T, Mathur R, Winkler H (2014) A new scenario framework for Climate Change Research: scenario matrix architecture. Clim Chang 122(3):373–386

Vengatesh V, Sangeetha V, Singh P (2016) Relationship between food production and consumption diversity in India: empirical evidences from cross-sectional analysis. Agric Econ Res Rev 29:139–148

Walker T, Schmiediche P, Hijmans R (1999) World patterns and trends in the potato crop: an economic and geographic survey. Potato Res 42:241–264

Watanabe S, Hajima T, Sudo K, Nagashima T, Takemura T, Okajima H, Nozawa T, Kawase T, Abe M, Yokohata T, Ise T, Sato H, Kato E, Takata K, Emori S, Kawamiya M (2011) MIROC-ESM 2010: model description and basic results of CMIP5-20c3m experiments. Geosci Model Dev 4:845–872

Watson J (ed) (2006) Golden arches east. McDonald's in East Asia (2nd ed). Stanford University Press, Stanford

Wiebe K, Lotze-Campen H, Sands R, Tabeau A, Van der Mensbrugghe D, Biewald A, Bodirsky B, Islam S, Kavallari A, Mason-D'Croz D, Müller C, Robertson R, Robinson S, Van Meijl H, Willenbockel D (2015) Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios. Envir Res Letters 10:085010

Wilkinson J, Rocha R (2009) Agro-industry trends, patterns and development impacts. In: da Silva C, Baker D, Shepherd A, Jenane C, Miranda-da-Cruz S (eds) Agro-industries for development. CAB International and FAO (Food and Agricultural Organization of the United Nations), Wallingford, pp 46–91

Woolfe J (1987) The potato in the human diet. Cambridge University Press, Cambridge